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AN ASSESSMENT OF LRTAP ACIDIFICATION OF SURFACE WATERS IN ATLANTIC CANADA

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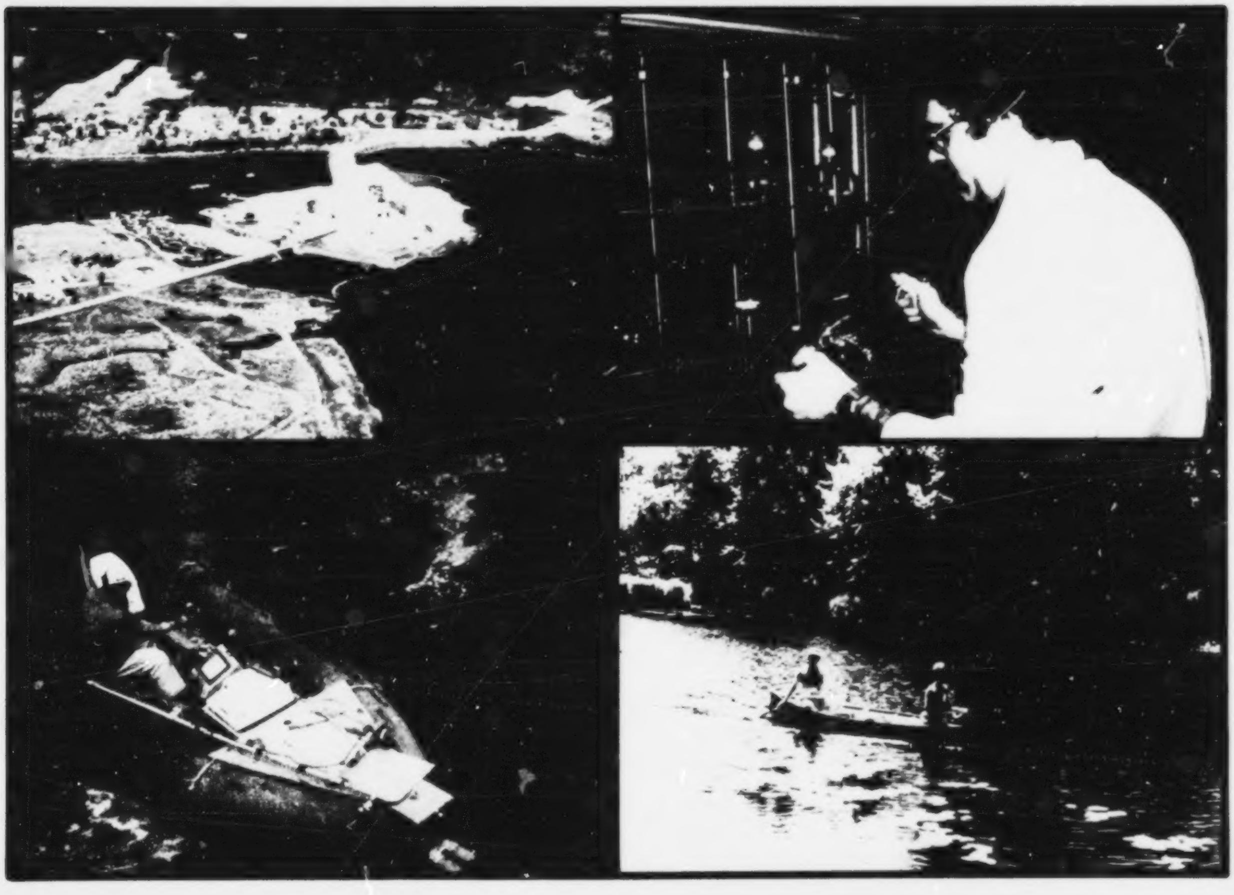

Canada

INLAND WATERS DIRECTORATE
ATLANTIC REGION
WATER QUALITY BRANCH
MONCTON, NEW BRUNSWICK

AN ASSESSMENT OF LRTAP ACIDIFICATION OF SURFACE WATERS IN ATLANTIC CANADA

IW/L-AR-WQB-87-121

by

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LRTAP Assessment

Table of Contents

Page
1. Abstract iii
2. Resume iv
3. Summary vi
4. Introduction 1
5. Data Presentation 6
   5.1 Data Sources 6
   5.2 Sample Station Locations 7
6. Data Validation 9
   6.1 Lake Data 9
   6.2 River Data (Spatial Distribution) 12
   6.3 River Data (Temporal Patterns) 13
7. Analytical Methodology 16
8. Regional Sensitivity 29
   8.1 Geology 29
      8.1.1 Nova Scotia 29
      8.1.2 Newfoundland 29
      8.1.3 New Brunswick 30
      8.1.4 Labrador 30
   8.2 Atmospheric Deposition 31
   8.3 Spatial Distribution 34
      8.3.1 Excess Calcium and Magnesium 34
      8.3.2 Dissolved Organic Carbon and Water Colour 41
      8.3.3 Excess Sulphate 49
      8.3.4 Alkalinity 70
      8.3.5 pH 83
      8.3.6 aluminium 91
      8.3.7 Ionic Ratios 94
      8.3.8 Models 97
9. Long Term Trends 105
   9.1 Statistical Approach 105
   9.2 pH 107
   9.3 Sulphate 111
   9.4 Additional Parameters 114
10. References 116

11. Acknowledgements 127
12. List of Plates 128
13. List of Tables 141
14. List of Figures 163
15. Appendix 1 264

1. ABSTRACT

This report analyses lake and river water quality data from Atlantic Canada in an attempt to provide a regional overview of the terrain sensitivity and the extent of LRTAP induced acidification. Southwestern Nova Scotia, northern Cape Breton Island and the west and south coast of Newfoundland have been identified as the areas which are the most sensitive to acidification. Surface waters in these areas show signs of acidification resulting from the combined effects of acid loadings from natural (i.e. organic acids) and anthropogenic (LRTAP) sources. Lake sulphate concentrations generally reflect the west to east deposition gradient with the highest values observed in New Brunswick and southwestern Nova Scotia. The most extreme acidification has occurred in Nova Scotia, with many of the hydrometric basins having lost on average more than 80 percent of the pre-acidification alkalinity. This is reflected in the pH data with 45 percent and 15 percent of the Nova Scotia lakes having values below 5.3 and 5.0 respectively.

Analysis of temporal changes indicated that pH values in Nova Scotia and Newfoundland rivers were significantly lower during the late 1960's and early 1970's while hydrogen ion exports peaked in 1973. This pattern agrees with the temporal pattern observed for the sulphur emissions in both the USA and eastern Canada.

2. RÉSUMÉ

Ce rapport présente une analyse des données sur la qualité des eaux de lacs et de rivières situés au Canada Atlantique. Il se veut être une tentative pour fournir une vue d'ensemble régionale de la sensibilité du terrain et de l'étendue de l'acidification induite par le TADPA. Le sud-ouest de la Nouvelle-Ecosse, le nord de l'île du Cap-Breton et les côtes ouest et sud de Terre-Neuve ont été identifiés comme étant les régions les plus sensibles à l'acidification. Les eaux de surface de ces régions montrent des signes d'acidification résultant des effets combinés de l'apport d'acides d'origine naturelle (i.e. acides organiques) et anthropogènes (TADPA). Les concentrations de sulfates mesurées dans les lacs reflètent généralement le gradient de déposition d'ouest en est, les valeurs les plus élevées étant au Nouveau-Brunswick et dans le sud-ouest de la Nouvelle-Ecosse. L'acidification la plus extrême s'est produite en Nouvelle-Ecosse où l'on a observé que plusieurs bassins hydrométriques ont perdu en moyenne plus de 80 pourcent de l'alcalinité existante avant l'acidification. Ceci est reflété dans les données de pH dont 45 pourcent et 15 pourcent des lacs de la Nouvelle-Ecosse ont des valeurs respectives plus basses que 5.3 et 5.0.

L'analyse des changements temporels a indiqué que les valeurs de pH dans les rivières de la Nouvelle-Ecosse et de Terre-Neuve furent significativement plus basses durant la fin des années 1960 et le début des années 1970, tandis que la quantité d'ions

hydrogène exportée avait atteint un maximum en 1973. Ce patron est en accord avec le patron temporel observé pour les émissions de soufre aux Etats-Unis et à l'est du Canada.

3. SUMMARY

Water quality data from lakes and rivers in Atlantic Canada sampled from 1980 to the present have been employed to give a regional overview of the terrain sensitivity and the extent of LRTAP induced acidification. In addition, long term data sets from selected rivers have been analyzed statistically to determine whether or not there have been significant patterns in water quality which could be related to changes in industrial emissions and/or atmospheric deposition. The results of the spatial and temporal analysis are summarized below.

1) Terrain sensitivity, as indicated by excess calcium and magnesium concentrations, was observed to be highest in southwestern Nova Scotia, northern Cape Breton Island and the west and south coast of Newfoundland. With few exceptions, the New Brunswick hydrometric basins had extremely low terrain sensitivities.

2) Water colours and dissolved organic carbon concentrations are elevated in southwestern Nova Scotia, along the eastern shore and in northern Cape Breton. The Newfoundland sites are generally more highly coloured than those in Nova Scotia, with the highest values observed in the northeastern portions of the province. This indicates that natural organic acidity is a significant but not necessarily a dominant contributor to the acidification of many aquatic systems in Nova Scotia and

Newfoundland. The Labrador and New Brunswick basins have low to moderate water colour and dissolved organic carbon concentrations, indicating minimal natural organic acidity effects.

3) Lake and river excess sulphate concentrations reflect the regional deposition gradient, provided that sites influenced by point source emissions and geological sulphate sources are excluded. The highest excess sulphate concentrations of LRTAP origin are observed in New Brunswick and southwestern Nova Scotia, while the lowest values are observed in Cape Breton, Newfoundland and Labrador. The low excess calcium and magnesium concentrations coupled with the high excess sulphate concentrations observed for southwestern Nova Scotia indicate a high potential for acidification. Similarly, the extremely high terrain sensitivity of basins in Cape Breton and western and southern Newfoundland indicate potential alkalinity loss even under a low sulphate loading scenario.

4) Excess sulphate concentrations in highly coloured Newfoundland lakes are considerably lower than values observed in clearwater basins. This suggests that highly coloured basins in Newfoundland may be either storing or exporting elemental or reduced sulphur compounds.

5) Excess sulphate concentrations in basins located in the vicinity of Halifax-Dartmouth are elevated due to the combined

effects of point source emissions, LRTAP and naturally produced mineral acids derived from the weathering of pyrites.

6) Excess sulphate (MTB) concentrations indicate that basins in southwestern Nova Scotia and in northern Cape Breton are strongly influenced by organic acids. This indicates that mineral and organic acids both contribute to the overall acidification process in selected basins in Nova Scotia. Similar observations can be made for the south coast Newfoundland basins which appear to have nearly equal contributions of mineral and organic acids.

7) Basins in southwestern Nova Scotia, along the eastern shore and the northern tip of Cape Breton have the lowest alkalinities and have on average lost more than 80% of the pre-acidification alkalinity. Basins located on the Great Northern Peninsula and along the south coast of Newfoundland also have low alkalinities. The alkalinity losses observed in southwestern Nova Scotia, Cape Breton and the west and south coast basins of Newfoundland can be partially attributed to the effects of LRTAP.

8) Cumulative probability plots of pH indicate that lakes in Nova Scotia have been the most severely acidified with 45 percent of the sites having pH values below the theoretical bicarbonate equivalence point and 15% of the sites having pH values less than 5.0. The lowest Nova Scotia pH values are

generally observed for basins underlain by granitic or Meguma Series rocks which are receiving a combination of natural and anthropogenic acid loads. The southwestern Nova Scotia and the northern Cape Breton basins have low pH values which can in part be directly attributed to LRTAP. Selected west and south coast basins (01YH, 01ZC) in Newfoundland are extremely sensitive precipitation receptors and thus even under a rather low atmospheric deposition scenario exhibit reduced lake pH values. The Labrador and New Brunswick basins all have high median pH values, indicating that the innate buffering potential in these two regions is sufficient to ameliorate the effects of atmospheric deposition and natural organic acidity.

9) Extractable aluminium concentrations tend to be closely related to water colour and dissolved organic carbon concentrations which suggests that much of the aluminium is complexed with organic ligands. The only indication of elevated labile aluminium concentrations are those basins situated near to Halifax, Nova Scotia which may have been acidified by high natural mineral acid loads.

10) A ratio which attempts to remove the natural organic acidity was calculated for the Nova Scotia basins and indicated that the most serious strong acid acidification has occurred in the vicinity of Halifax. Basins in southwestern Nova Scotia (01DA, 01EA, 01EC, 01ED) and in Cape Breton (01EO) have also experienced some mineral acidification, indicating that LRTAP

is a significant contributor to the overall acid load. This is particularly apparent for basin 01DA in southwestern Nova Scotia and 01FD in northern Cape Breton.

11) The Henriksen models support the observations made from the chemical parameters and ionic ratios and agree well with precipitation pH data. In general, the models indicate that approximately 60% of the lakes in southwestern Nova Scotia and northern Cape Breton have been acidified due to combined mineral and organic acid loads. The Newfoundland basins also show evidence of acidification but to a much lesser extent than was observed for the Nova Scotia basins.

12) Long term trend analysis has indicated that pH values in Nova Scotia and Newfoundland rivers were significantly lower during the late 1960's and early 1970's than they are at present. Hydrogen ion exports confirm this observation with peak values observed circa 1973. This pattern agrees well with the temporal pattern observed for sulphur emissions in both the USA and Eastern Canada.

4. INTRODUCTION

Approximately 8% of Canada's total surface area is covered by lakes and rivers while an additional 12% is in the form of wetlands. This resource is of tremendous importance to Canada as it not only is used for drinking water supplies, electrical generation, transportation, industry and recreation but it also supports other natural resources such as fisheries and forestry. Although it is difficult to estimate, current evaluations indicate that the aquatic resource adds between $8 billion - $23 billion per annum to our national wealth (Pearce 1985).

World attention was drawn to the problem of transboundary air pollutants and their deposition on surface waters, when Sweden and Norway documented the so-called acid rain phenomenon (Barrett and Brodin, 1955, Grahn et al., 1974; Gjessing et al., 1976; Douland et al., 1976). From these Scandinavian studies, scientists in North America realized that a parallel situation existed between the United States and Canada. The contributing factors to this problem are large emission source areas such as the Ohio Valley and parts of Southern Ontario, a meteorological pollutant transport mechanism and sensitive receptor areas in eastern Canada and the north-eastern United States. From North American pH isopleth maps (MOI, 1983), it is readily apparent that much of north-eastern United States and Eastern Canada is receiving precipitation with pH values much lower than the expected value of approximately 5-5.6.

The Atlantic provinces lie in the mid-latitude westerlies downwind of major emission sources (Shaw, 1979) and are receiving acid precipitation due to long range transport of atmospheric pollutants (LRTAP), principally the oxides of sulphur and nitrogen. Several precipitation monitoring networks (Shaw 1979; Underwood et al. 1986) have shown reduced pH values and elevated sulphate levels while remote station data from CAPMoN (Vet et al., 1986) and Underwood et al. (1986) have both shown west to east deposition gradients which are characteristic of LRTAP. Underwood et al. (1986) have shown that sulphate deposition in Atlantic Canada is much greater than nitrogen deposition indicating that sulphuric acid is the dominant strong mineral acid in precipitation. These authors have also demonstrated a good relationship between atmospheric sulphate deposition and lake sulphate concentrations which suggests that in-lake sulphate concentration can be employed as a surrogate of H^+ ion loading.

Although atmospheric loads of acidic compounds are important, the geochemical processes within the watershed ultimately determine the aquatic response to LRTAP. Much of Atlantic Canada is underlain by siliceous and granitic bedrocks which are resistant to chemical weathering. This coupled with thin soil overburdens have resulted in dilute surface waters which are sensitive to acid precipitation. Clair et al. (1981) using limited surface water data have prepared spatial maps of selected LRTAP related parameters which have indicated that southwestern Nova Scotia and much of insular Newfoundland are extremely sensitive to acidification. Similarly, Scruton (1983; 1984) has shown that the west and south coasts of insular Newfoundland and the southeastern portion of Labrador also have high terrain sensitivity. Several other studies (Kerekes, et al., (1982); Wiltshire et al., (1981); Scruton, 1984; Howell, 1986) have indicated that lakes and rivers with low pH levels and total alkalinity concentrations near to 0.0 mg/L are not uncommon in Atlantic Canada. This suggests that even though the present atmospheric deposition of sulphate is at or below the target loading value of 20 kg SO_4/ha/yr (MOI, 1983), the potential for acidification of surface waters in Atlantic Canada is high. Studies of water chemistry changes over time have indicated that the pH levels in lakes (Watt et al., 1979; Wiltshire and Machell, 1981) and rivers (Thompson 1986) in Atlantic Canada are presently lower than they were during the 1950's. Similarly, Clair and Whitfield (1983) using Box Jenkins trend analysis noted significantly decreasing pH trends from 1965 to 1973 for several rivers in Nova Scotia. However, low pH values cannot be attributed entirely to LRTAP as many of the surface waters in the region have significant sources of natural organic acidity. Many of the temporal studies have indicated concomitant increases in sulphate during the low pH periods but given the analytical difficulties associated with the measurement of sulphate (Howell and Pollock, 1986), these findings must be viewed with caution. Despite this, LRTAP has been implicated in recent changes in surface water chemistry in this region and has also been linked to reduced angling yields from several southwestern Nova Scotia Atlantic salmon rivers (Watt et al. 1983).

Although numerous studies have adequately addressed specific LRTAP related topics in Atlantic Canada, attempts at a regional overview of sensitivity and degree of acidification have not been entirely successful. This stems from the fact that numerous government and private sector agencies have been actively involved in LRTAP research and water quality monitoring. This multi-faceted approach has severely hindered the development of a single, comprehensive data base.

A consequence of this is that many of the regional and/or provincial based reports have been forced to consider a small percentage of the available water chemistry data. This has led to many contradictory results particularly when attempting to estimate the percentage of resources at risk due to LRTAP (Underwood and Schwartz, 1986). To reduce this shortcoming, the Water Quality Branch has incorporated water quality data from the major agencies involved in the LRTAP studies, into the Inland Waters Directorate National Water Quality data base (NAQUADAT). Although the NAQUADAT data base is not complete due to the fact that some of the smaller data sets have not been possible to obtain, this process has yielded the most comprehensive data base of surface water quality presently available in Atlantic Canada. Using this data base, it is intended to make an assessment of not only the terrain sensitivity but also the present extent of acidification of the aquatic resources of Atlantic Canada. In addition, some of the more continuous historical data records will be utilized to investigate water quality trends or changes over time.

5. DATA PRESENTATION

5.1 Data Sources

The data used in this report are all stored on NAQUADAT, the Inland Waters Directorate of Environment Canada water quality data base. Although many of these data were collected specifically for LRTAP related studies, the data set also includes non-specific water quality monitoring data. The Nova Scotia data were collected principally by the Inland Waters Directorate, Canadian Wildlife Service (Environment Canada) and the Nova Scotia Department of the Environment. The data base also includes stations which have been sampled by the Department of Fisheries and Oceans, the Environmental Protection Service of Environment Canada, Nova Scotia Department of Health as well as various non-governmental researchers. The Newfoundland and Labrador data set is comprised of stations sampled, almost entirely, by Inland Waters Directorate, Fisheries and Oceans and the Newfoundland Department of the Environment. In addition, several of the sites in Labrador and insular Newfoundland were sampled by the Canadian Wildlife Service. As was the case in Nova Scotia and Newfoundland, most of the New Brunswick stations were sampled by the Inland Waters Directorate and the Department of Fisheries and Oceans. A small number of these stations were sampled by the New Brunswick Department of the Environment and the Canadian Wildlife Service. Prince Edward Island is not considered in this report as the available surface water chemistry data provides poor spatial coverage and the province is not geologically sensitive to LRTAP.

5.2 Sample Station Locations

These data have been collected by numerous agencies for a variety of purposes and thus must be used cautiously when considering the spatial variability of selected water quality parameters as it relates to acidification of the region. Not all of the provinces or portions of the provinces are equally covered by the water quality stations and thus use of the results of these data to make provincial predictions is not entirely valid.

The locations of the Nova Scotia lake stations are presented in Figure 1 and indicate that the sampling stations are not evenly distributed over the province. In addition, Table 1 indicates the hydrometric basin groupings which will be used for the spatial distribution discussions. This grouping of hydrometric basins was necessary to increase the sample size of under-represented basins. The greatest concentration of stations occur in southwestern Nova Scotia and in the vicinity of Halifax-Dartmouth. As many of the stations were originally established for specific LRTAP programs, the majority of the Nova Scotian sites are situated in geologically sensitive areas (i.e. granitic and Meguma Series bedrock). The much less sensitive area from Truro to the New Brunswick border has been sampled very sparsely. Thus any predictions based on the Nova Scotia data should be considered as a worst case scenario rather than indicative of the province as a whole.

The Newfoundland lake station locations are presented in Figure 2 and the hydrometric basin groupings are listed in Table 2. Unlike Nova Scotia, the Newfoundland sites are rather well distributed with only a few basins being obviously under-represented. Thus, results of the spatial distribution data for insular Newfoundland are expected to give a reasonable indication of the water quality conditions of the province.

Plots of the locations of lake stations for Labrador and river stations for New Brunswick are presented in Figures 3 and 4 respectively. Due to the limited data sets, it was necessary to pool several hydrometric basins for both New Brunswick (Table 3) and Labrador (Table 4). The Labrador stations are concentrated in the south and central regions while the northern portion of the province is poorly represented. In New Brunswick, nearly all the lake stations are concentrated in the most sensitive, southwestern portion of the province. The river data gives a better geographical coverage, however, the stations tend to be concentrated on interjurisdictional waters such as the Saint John River. Thus, although the Labrador and New Brunswick data can be employed to indicate spatial patterns in water quality, they cannot be used to make province-wide predictions on the extent of acidification.

6. DATA VALIDATION

6.1 Lake Data

The lake water chemistry data utilized in this report were extracted from the Environment Canada NAQUADAT data storage system and included samples collected in the Atlantic Region during the period 1980 to 1985. Although this time interval will exclude some lakes sampled prior to 1980, it was felt that this approach to data selection would minimize difficulties in data interpretation due to the effects of temporal trends and variable analytical methodology.

For each sample, data were retrieved for the eighteen water quality parameters listed in Table 5. Any samples which had data for less than five of these selected parameters were not included in the primary data set. This initial data extraction yielded a total of 1861 water chemistry samples from 684 individual lakes. Prior to data validation, equivalent major ion concentrations, ion balances, balance standard deviations, theoretical conductivity, and the sum of constituents were computed for each sample. In addition sea-salt corrected concentrations for sulphate, calcium and magnesium were calculated using the factors presented in Table 6.

The main validation technique employed was the standard deviation of the ion balance, with an acceptance region ranging from -1 to +1. The standard deviation was used rather than the percent error, as this technique is less dependent on the magnitude of the sum of constituents.

The calculated ion balances included calcium, magnesium, potassium, sodium and hydrogen ion concentrations in the sum of cations, and bicarbonate, sulphate (MTB) and chloride concentrations in the sum of anions. The alkalinity measurements in this data set included both double fixed end-point total alkalinity and Gran plot alkalinity, depending on the initial pH of the sample. Some samples had both total and Gran plot alkalinity measurements and in these cases the Gran values were always given preference over total alkalinity.

Of the 1861 samples, 187 or 10% were flagged due to unacceptable ion balance standard deviations. Of these samples, 120 were missing one or more of the major ions and thus the high difference between the sum of cations and anions did not necessarily indicate unacceptable water quality data. The 67 samples which had complete analysis and unacceptable ion balance standard deviations were deleted from the data set. In addition, thirty samples from McGinty Lake (01NS01ED0028) were removed as the water chemistry data were vastly different from both recent and historical data from this site, indicating possible sample misidentification. This data screening resulted in a data set of 1774 water quality samples from 670 lakes.

In addition to the standard deviation of the ion balance, comparison of the theoretical and actual specific conductance was employed as a further quality control technique. An unacceptable difference of 10% was established and non-compliance with this limit warranted further validation but not necessarily deletion of the entire sample. The factors used to calculate the theoretical conductivity are presented in Table 7. Figure 5 indicates that there is generally good agreement between the calculated and measured specific conductance with the majority of the unacceptable samples resulting from missing major ions. Although poor agreement between theoretical and measured specific conductance did not result in deletion of samples, it did warrant a more critical assessment of the major ion concentrations of flagged samples. The ratio of the sum of constituents with specific conductance was also used as an indication of poor quality data. Natural waters are expected to have ratios ranging from 0.5 to 0.7 and thus values outside this range were flagged. Figure 6 indicates that a large percentage of the samples have ratios which are less than the 0.5 lower limit. Although some of these low values are the result of missing major ions, many are due to the large number of low pH samples included in this data set. As hydrogen ion has a much greater theoretical conductivity than the other major ions, ratios less than 0.5 are to be expected in acidic waters. In addition, as organic anions are not included in the sum of constituents, samples which have low pH values due to organic acidity would be expected to have even lower ratios than samples with low pH values due to strong mineral acidity. Thus, as with the theoretical conductance, the ratio of the sum of constituents and specific conductance was used to flag possible data problems but not to delete samples.

Following this water quality validation, the data set was subjected to a routine which calculated median values for each site. Although 75 percent (506) of the 670 sites had only a single sample, the remaining 25 percent of the sites ranged from 2 to 175 samples. A breakdown of the data distribution by province is given in Table 8. In order to make this data set as complete as possible, attempts were made to include data not presently stored in NAQUADAT. This resulted in the addition of 201 Nova Scotian lakes sampled by the Nova Scotia Department of the Environment and 47 Labrador lakes sampled by the Department of Fisheries and Oceans. The Nova Scotia data are average conditions computed from a series of samples while the Labrador data represent single samples. Inclusion of these data resulted in a final data set of 457 Nova Scotian, 335 Newfoundland, 85 Labrador and 41 New Brunswick lakes, giving a grand total of 918 lakes.

6.2 River Data (Spatial Distribution)

Water quality data from rivers sampled in the Atlantic Region were also retrieved from NAQUADAT and encompassed the same time period and parameter list as the lake data. This initial extraction resulted in the retrieval of 12,818 samples from a total of 344 rivers. Due to the large number of samples and the high frequency sampling at many of the sites, validation was carried out on median concentrations for each site rather than on individual samples.

The validation procedures employed for the river data were identical to those outlined for the lake data set. Of the 344 rivers, eighteen sites had ion balance standard deviations which did not meet the established acceptance criteria. Eleven of these stations were deleted while the remaining seven were accepted as the poor ion balances were the result of missing major ions. Figure 7 presents the relationship between the theoretical and measured specific conductance and indicates that with very few exceptions there is good agreement. The majority of the outliers are below the 1:1 line suggesting that the theoretical values are low due to missing major ions. As was observed for the lakes data set, a large number of the sum of constituent to specific conductance ratios were below the expected 0.5 to 0.7 range (Figure 8). Once again this distribution probably reflects the large number of sites with high H^+ and organic anion concentrations. The validation procedure resulted in a final data set of 333 rivers of which 141, 101, 64, 26 and 1 are located in Nova Scotia, New Brunswick, Newfoundland, Labrador and Prince Edward Island respectively.

6.3 River Data (Temporal Patterns)

Quality control routines were run on the temporal river data to check for the occurrence of possible errors in either chemical analysis or data entry to the computer file.

The first data quality analysis involved calculations of ion balances but due to missing parameters, this technique had rather limited usefulness, especially for the pre-1981 data sets.

Because the ion balances were of relatively little help, a simple statistical analysis was used to identify anomalous, outlier data points. This involved the calculation of a 95% confidence interval comprised of ± 2 standard deviations of the mean and a computer program to flag all outlier data points that were beyond this confidence interval. The data set for the sampling date that included any flagged data point was then inspected, and was eliminated from the data set if there was either an obvious case of contamination by mineral acid used in the cleaning of sampling bottles, or if there was an obvious case of order-of-magnitude error, which could have arisen from either an incorrect data entry, or an analytical problem.

Overall, this was a fairly conservative approach and resulted in relatively few removals of data from the original file. Out of a total of more than 3000 individual records (i.e. sets of analyses for a particular watercourse on a particular date), only 21 were removed. Of these 16 were obviously contaminated by mineral acid from the bottle washing procedure and the others had order-of-magnitude problems with several individual constituents. Beyond this removal of data sets, some individual data points (i.e. analyses for particular constituents for a particular watercourse on a particular date) were also removed, because they differed from the overall average for their watercourse by approximately an order of magnitude. However, out of a total of more than 48,000 individual data points, only 91 were removed for this reason. The most common offender was nitrate, which accounted for 28 of the cases. Thus a very small fraction of the total data set was eliminated for these reasons. This reflects both the rather conservative approach used and the high analytical quality of the data.

In addition, for some of the watercourses, there was a small number of duplicate or triplicate analyses of samples for particular dates, taken for quality control reasons. In these cases, the median values for each constituent among multiple analyses was calculated and retained on the file.

Finally, seasalt-corrected values (excess) of sulphate were computed. These were based either on ratios of sulphate:chloride, or magnesium:chloride, and followed Watt et. al. (1979).

7. Analytical Methodology

Specific Conductance (NAQUADAT 02041)

Electrical conductance or conductivity is the ability of a substance to conduct an electric current. Distilled water has a very low electrical conductance generally ranging from 0.1 to 4 microSiemen per centimetre at 25°C. The presence of charged ionic species in solution makes the solution conductive. As ion concentrations increase, conductance of the solution increases; therefore, the conductance measurement provides an indication of ion concentration (Hem 1971).

The ionic chemistry of local waters is an integration of the net effects of basin hydrogeochemistry and the prevailing water chemistry can be used as an indicator of the buffering capacity existing in the basin and therefore its sensitivity to acidification. Sensitivity based on specific conductance has been very generally divided into three categories (NRC, 1981), highly sensitive 0-35 uS/cm, moderately sensitive 22-78 uS/cm and least sensitive >60 uS/cm.

In the laboratory specific conductance is determined using a conductivity cell and meter, calibrated using standard potassium chloride solutions. The conductivity is read directly and corrected to 25°C (WQB 1979).

pH (NAQUADAT CODE 10301)

The pH of natural waters is a measure of the hydrogen ion concentration in solution. It is given by the negative logarithm of the activity of the hydrogen ion in solution, however, for practical purposes it is approximated by

$$pH = -\log_{10} [H^+]$$

where $[H^+]$ is the hydrogen ion concentration in moles per litre.

With modern electrodes and buffer solutions the pH of natural waters can be accurately determined. The problems arise because of the highly variable nature of this parameter within the aquatic system, which cause difficulty in determining whether a real change in pH levels has occured.

As pH indicates the balance between acids and bases, the presence of carbonates, hydroxides, bicarbonates, carbonic acid, mineral acids or organic acids can influence the hydrogen ion concentration and hence the pH value. Gains or losses of carbon dioxide due to respiration/photosynthesis may cause diurnal changes of pH of up to 1 unit. Build up of carbon dioxide levels in ice covered waters will also influence the pH of the system. A pH measurement taken "in situ" or at the moment of sampling may represent the actual conditions but if the water is placed into a sample bottle and the pH determined at a later date the measured pH may have no relation to the original conditions (Hem 1971). For the purposes of this report, where pH data were collected during different seasons, at different times of the day by varying methods, where it is necessary to compare data from one waterbody to another, and between samples from the same waterbody, the laboratory pH measurement was considered to be the most stable and comparable.

The method used (NAQUADAT 10301) is an electrometric measurement. A glass electrode in combination with a reference potential provided by a saturated calomel electrode is used for the pH measurement (WQB 1979). The pH meter is calibrated using two different buffer solutions in the approximate pH range of the samples to be measured. Values are reported to the nearest 0.1 pH units.

Alkalinity (Acid Neutralizing Capacity) (NAQUADAT CODES 10101 and 10110)

The total alkalinity or acid neutralizing capacity (ANC) of a natural water is the reserve of bases in solution which become protonated as acid is added thus neutralizing that acid. For most clearwater lakes and streams the ANC is comprised almost entirely of bicarbonate ions, (HCO^-_3). However, in the Atlantic Region, highly coloured (brown) waters are common. In these waters organic bases contribute to the ANC.

For waters whose ANC is dominated by the bicarbonate system the alkalinity is derived mainly from the weathering of calcareous material within the watershed. The total alkalinity is usually expressed as

$$\text{alkalinity} = [\text{HCO}^{-3}] + 2[\text{CO}_3^{--}] + [\text{OH}^-] - [\text{H}^+]$$

[] denotes concentration in moles/litre.

Two methods are employed at the Water Quality Branch Moncton Laboratory for determining alkalinity. These are NAQUADAT codes 10101 Total Alkalinity and 10110 Gran Plot Alkalinity.

Method 10101 Total Alkalinity is a potentiometric titration method utilizing a double end point.

An aliquot of sample is titrated with a standard solution of sulphuric acid to pH 4.5 and then to pH 4.2. The total alkalinity is determined from both titrations volumes (WQB 1979). Using the double end point method enables the actual inflection point or equivalence point pH of the titration to be determined. An automatic titration system is used. The detection limit of this method is 0.5 mg/litre $CaCO_3$. That is, alkalinities less than 0.5 mg/litre or negative alkalinities are not measured by this method.

Method 10110 Gran Alkalinity is only suitable for soft waters and has no assigned detection limit. This method gives an estimate of the alkalinity deficit or negative alkalinity where the waters have been acidified. The method used by WQB Laboratory Moncton is as follows.

Take an aliquot of 100 mL of sample and add 0.25 mL 1N potassium chloride then titrate to pH 3.7 with 0.001 N hydrochloric acid. A pH meter, autoburette and printer record the incremental volumes added together with the corresponding pH. The volume corrected H^+ concentration is plotted versus the volume of added acid. The alkalinity is determined from extrapolation of the linear portion of the curve on the abscissa. The results of this titration may be either positive or negative.

Calcium (NAQUADAT 20110)

For most natural fresh waters calcium is the principal cation. It occurs as an essential element in many igneous - and sedimentary rock minerals (Hem 1971). It is relatively abundant in the earth's crust and is readily soluble in water. The major factors limiting the solubility are the equilibria involving carbonates. The carbonic acid in clean precipitation (pH 5.6) weathers the soil and rock in a watershed to produce a flux of base cations. If strong acids are present in the precipitation (pH <5.6) there will be additional protons available for cation exchange during the weathering process. During this process the acid is neutralized by the bases in the minerals (proton-cation exchange) (Bobee 1982).

The cation concentration in surface waters is thus a measure of the watershed's capacity to neutralize acid precipitation.

Calcium concentrations are determined by an automated atomic absorption method (NAQUADAT 20110). An autoanalysis unit consisting of a sampler, manifold and proportioning pump are used. A secondary sample line and transmission delay line are incorporated so that the sample can be diluted if necessary. The absorbance is measured spectrophotometrically at 422.7 nm. The detection limit is 0.1 mg/litre calcium.

Magnesium (NAQUADAT 12107)

Magnesium like calcium is an alkaline-earth metal. It is an abundant element and a common constituent of natural waters. The major source of magnesium is the weathering of rocks and minerals. Dolomitic [Ca Mg $(CO_3)_2$] sedimentary rocks are the principal contributors of magnesium to water (McNeely 1979).

The analytical method for determining magnesium concentrations in water (NAQUADAT 12107) is identical to that for calcium, except the absorbance is measured at 285.2 nm.

Sodium (NAQUADAT 11103)

Sodium is the most abundant member of the alkali-metal group. The amounts of sodium held in evaporate sediments and in solution in the ocean are an important part of the total (Hem 1971). When sodium has been brought into solution, it tends to remain in that status. For most of the water bodies studied in this paper the only source of sodium is the atmospheric deposition of marine aerosols.

Sodium in water is determined using an automated flame photometry method. A sample aliquot is mixed with a lithium nitrate solution and aspirated in a flame photometer. The light emission is measured at 589 nm and compared with that of an internal lithium solution at 670 nm. The flame photometer is calibrated using standard sodium solutions and the detection limit is 0.1 mg/litre.

Turbidity (NAQUADAT 02073)

Turbidity is a measure of the suspended particles such as silt, clay, organic matter, plankton and microscopic organisms in water which are usually held in suspension by turbulent flow and Brownian movement. (McNeely 1979).

Turbidity is measured by photometry on a Hach Turbidimeter. A light beam is passed through the shaken sample. The light scattered at 90 degrees to the beam-axis is measured by photoelectric cells. The instrument is calibrated using standard hydrazine sulphate Hexa methylenetetramine solutions, and standardized with a polyacrylic plastic rod containing special turbidity material. The detection limit is 0 Jackson Turbidity Units (WQB 1979).

Chloride (NAQUADAT 17205)

Chloride is a major inorganic anion that occurs in variable concentrations in natural waters. Except for areas near brine or salt deposits or areas close to the ocean and under the influence of marine aerosols, most chloride in freshwaters results from anthropogenic activities. Chloride is considered a conservative ion in freshwaters and its circulation in the hydrologic cycle is largely through physical processes. For this reason chloride data are often used to determine dilution effects. Chloride ions in waters of Atlantic Canada are almost totally marined derived and thus chloride concentrations are often used for seasalt corrections.

Chloride concentrations are determined using a specific ion electrode.

Potassium (NAQUADAT 19103)

Although potassium constitutes about 2.5% of the earth's crust and is one of the principal alkalies present in soil, it is only found in quantities of a few parts per million in water. Both sodium and potassium are alkali metals with similar chemical characteristics except for their behaviour to weathering. After leaching, sodium remains in solution, whereas potassium usually is incorporated into new stable minerals (e.g. clay minerals) (McNeely, 1979).

The analytical method for potassium (NAQUADAT 19103) is identical to that for sodium except the light emission is measured at 768 nm. The detection limit is 0.1 mg/litre.

Sulphate (NAQUADAT CODES 16303, 16304, 16309)

Sulphate (SO_4^{2-}) is the stable, highly oxidized form of sulphur. Unlike the other major ions, sulphate in natural freshwaters in eastern Canada usually is not of geologic origin. There are specific areas where gypsum or pyrites occur but for the most part the sulphate in these waters results from atmospheric deposition. Both wet and dry deposition contain sulphates which result primarily from the combustion of fossil fuels and base metal smelting. In coastal areas, marine aerosols also contribute sulphate to the deposition load.

Two analytical methods are currently employed to determine sulphate levels in freshwaters. The first method (NAQUADAT 16304) is a colourimetric method on an autoanalyzer with barium chloride and methylthymol blue (MTB). Sulphate ion reacts with an equimolar solution of barium chloride and MTB at pH 2.3-3.0. When the pH is raised to 12.5 - 13.0 the excess barium reacts with the MTB. The absorbance of excess MTB is measured at 460 nm. The detection limit is 1.0 mg/litre sulphate. However this method is unsuitable for coloured waters (colour > 30 units) (Howell and Pollock; 1986) as the dissolved organic carbon in the water interferes with the method to indicate higher sulphate values. (Kerekes et. al., 1984).

The second method (NAQUADAT 16309) uses ion chromatography. The sample is injected into the stream of eluant, which is pumped through two columns (pre-column & separator column) which are packed with low capacity anion exchanger resin in the $CO_3^{=}/HCO_3^{-}$ form. The ions of interest are separated based on their affinity for the exchange sites of the resin bed. The suppressor column reduces the background conductivity of the eluant to a negligible level by converting the anions in the sample to their respective acid forms. The conductivity of these separated anions are measured by using a conductivity cell. Anions are identified by their retention times compared to the known standard. The concentration of the anions is calculated by comparing the peak area of the sample to the peak area of a standard. The detection limit for this method is 0.5 mg/litre sulphate.

Prior to 1973, sulphate concentrations were determined using a titrimetric method with Thorin as an indicator (16303). The sample is first passed through an ion exchange column, after which a 10 mL aliquot is added to 40 uL of alcohol and 2 drops of Thorin indicator. The pH is then adjusted to 3.8-4.0 with NH_4OH (1:99 solution) until the solution turns pink. A 1:99 solution of HCl is then added until the pink colour disappears. The solution is then titrated with a $BaCl_2$ solution until the sample turns pink. This method is applicable for surface waters in the range of 5 mg/L to 150 mg/L of sulphate (ASTM, 1969).

Dissolved Organic Carbon (DOC) (NAQUADAT 06107)

By definition DOC refers to the measurement of carbon which is organically bound, in waters that have passed through a 0.45 micron filter. The bulk of the organic carbon in water is usually composed of humic substances leached from soils, bogs or partly degraded plant materials and are found in dissolved, colloidal or particulate forms. These materials are responsible for the brown colouration of many waters in Atlantic Canada. Composed partly of high molecular weight carboxylic acids, they impart natural acidity to freshwaters and can also complex many metals, thus reducing their bio availability and potential toxicity (Jones et al., 1986). Other organic compounds which may be found include sugars, amino acids and organic bases.

DOC is measured by the following method. The acidified sample is sparged with nitrogen gas to remove inorganic carbon and the remaining organic carbon compounds are converted to carbon dioxide gas in an in-line acid-persulphate-UV digester. After dialysis the carbon dioxide concentration is determined colourimetrically by measuring the loss of colour in a borate buffered alkaline phenolphthalein solution. The detection limit is 0.5 mg/litre carbon.

Colour (NAQUADAT 02011)

Although natural mineral components such as iron and manganese impart colour to waters, the more usual common sources are organic materials such as humic substances, tannins and lignins. Colour can be used as an indicator of dissolved organic carbon for some waterbodies.

The apparent colour (i.e. colour derived from both dissolved and suspended materials) is measured by a visual comparison. A shaken sample in a Nessler tube is compared with standard colour solutions. (WQB, 1979).

Extractable aluminium (NAQUADAT 13305)

Although aluminium is the third most abundant of the elements in the earth's outer crust, it only occurs in dissolved form in natural waters at low concentrations since it is usually sorbed to sediments or precipitated from solutions. The exceptions are waters of low pH (Hem, 1971). The solubility of aluminium is negligible at pH's greater than 5.5 but below this threshold concentrations can increase significantly.

At the Moncton Laboratory the extractable aluminium (NAQUADAT 13305) is measured. That is, the dissolved concentration plus the concentration of metal from the suspended materials dissolved by dilute mineral acid is measured.

Dilute mineral acid (HNO_3 at 0.2%) is added to the sample, which is shaken and left to stand overnight. A sample of this solution is adjusted to pH = 8.00 with buffer solution. 8-Hydroxy Quinoline is added and then the solution is extracted with MIBK (Methyl Iso Butyl Ketone). The absorbance of the extract is measured at 309.3 nm and compared with those of standard aluminium solutions. The detection limit is .01 mg/litre.

8. REGIONAL SENSITIVITY

8.1 Geology

This section will present a brief overview of the dominant geological formations underlying the river and lake stations included in this report. As the water chemistry discussion is based on the Water Survey of Canada hydrometric basin delineation, the regional geology will also be addressed on a basin by basin basis. Although this may lead to some redundancies, it is felt that comparison of the geological features of the region to the surface water chemistry will be greatly simplified by this approach. It should be noted that the provincial geological summaries may provide an adequate overview of the major geological features and therefore the basin by basin descriptions are presented in Appendix 1.

8.1.1 NOVA SCOTIA

Figure 9 presents a map of Nova Scotia indicating the general geological structure of the province. Descriptions of the significant geological formations are presented in Table 9. Table 10 presents a summary of the geological structure of each hydrometric basin in the province.

8.1.2 NEWFOUNDLAND

A map of Newfoundland indicating the major geological formations of the province is presented in Figure 10 and a description of the geology is presented in Table 11. Table 12 gives a breakdown of the bedrock geology by hydrometric basin.

8.1.3 NEW BRUNSWICK

A map of New Brunswick indicating the generalized geological formulations of the province is presented in Figure 11. A description of the geological formations is given in Table 13 while Table 14 gives a breakdown of the bedrock geology by hydrometric basin.

8.1.4 LABRADOR

A map of Labrador indicating the major geological formations of the province is presented in Figure 12. A description of the geological formations is given in Table 15 while Table 16 presents a breakdown of the bedrock geology by hydrometric basin.

8.2 Atmospheric Deposition

As Atlantic Canada is situated downwind from industrial sources and has been shown to be affected by LRTAP, several agencies have been involved in monitoring precipitation chemistry. These data have been used not only to track major emission sources (Shaw, 1979) but also to characterize and quantify the west to east deposition gradient (Thompson and Hutton, 1985).

Underwood et al. (1986) analysed precipitation data collected from 8 Nova Scotia stations during the period 1977 to 1980 and observed a rather well defined pH and sulphate concentration gradient. The rural station annual average pH values ranged from a low of 4.45 in southwestern Nova Scotia to a high of 4.86 in Cape Breton confirming the existence of a distinct southwest to northeast deposition gradient. The lowest average annual pH value (4.38) was recorded near Halifax-Dartmouth and has been attributed, in part, to a local point source emission. The sea salt corrected (excess) sulphate deposition pattern is similar to that observed for pH, having a southwestern Nova Scotia composite value of 47.0 $meq/m^2.yr$ as compared to a value of 38.1 $meq/m^2.yr$ for the northeastern portion of the province. As was observed for pH, the extreme sulphate deposition value of 86.9 $meq/m^2.yr$ was observed near to Halifax. Combining these precipitation pH data with more recent data collected by the CAPMoN network (Vet. et al., 1986) and the Newfoundland Department of the Environment (unpublished data) gives a reasonable view of the deposition gradient over Atlantic

Canada (Figure 13). However, it must be noted that these data sets span a period of record of approximately 7 years (1977-1984) and thus some discrepancies are to be expected due to changing emissions and variable annual precipitation rates. In addition, many areas are not adequately monitored which further hinders the characterization of the regional pattern of atmospheric deposition.

Excluding the Halifax data, the lowest precitation pH values in Atlantic Canada are observed in southwestern Nova Scotia. The New Brunswick data are restricted to a single CAPMoN station situated in the eastern portion of the province and as such provide limited insight into the deposition gradient. However, the average precipitation pH for this station is similar to the Kejimkujik National Park value which suggests that New Brunswick is being impacted to at least the same extent as southwestern Nova Scotia. Cape Breton Island and insular Newfoundland have similar precipitation pH values, being somewhat higher than those recorded in New Brunswick and mainland Nova Scotia. Although the Newfoundland data are limited, the recent CAPMoN data indicates a slightly higher precipitation pH at Bay D'Espoir than at Cormack suggesting the existence of a slight west to east gradient. The one Labrador CAPMoN station had an annual precipitation pH which is similar to that recorded for the west coast of Newfoundland. It is interesting to note that the similarity of the Cape Breton and the insular Newfoundland pH values is contrary to the expected deposition gradient. Although it is possible that Newfoundland receives additional atmospheric deposition from weather systems

tracking to the north of Nova Scotia, it may be that this gradient anomaly is solely a consequence of variations in annual precipitation due to orographic effects.

The excess wet sulphate deposition (meq/m^2.yr) estimates for stations in Atlantic Canada are presented in Figure 14. The 1984 CAPMoN data support the existence of a well defined west to east deposition gradient, with the highest values observed in New Brunswick and southwestern Nova Scotia. Deposition values are slightly lower in eastern Nova Scotia and New Brunswick and lower still on insular Newfoundland. The Baie D'Espoir excess sulphate deposition value (27.2 meq/m^2.yr) is slightly lower than the value recorded at Cormack (29.1 meq/m^2.yr), indicating a slight deposition gradient across the island. By far the lowest excess sulphate deposition rate (15.6 meq/m^2.yr) recorded in Atlantic Canada during 1984 was observed at the Goose Bay CAPMoN station. However, it must be stressed that despite this low deposition rate, low annual precipitation rates result in precipitation pH values and sulphate concentrations which are comparable to those found for insular Newfoundland stations. The sulphate deposition rates for Nova Scotia precipitation monitoring stations presented by Underwood et al. (1986) are somewhat higher than the values given by Vet et al. (1986). However, it must be considered that these data were averaged for the period of 1977-1980 and may represent a period of higher industrial emissions. Despite the discrepancies in the deposition estimates, these data also verify the existence of a well defined west to east gradient in wet sulphate deposition.

basins in southwestern and eastern Nova Scotia. The basins on the south coast of Newfoundland are extremely variable, having median water colours ranging from 20 to 40 Hazen units. As was the case for Nova Scotia, the Newfoundland river data are sparse and therefore provide little information on spatial patterns. However the data that were available compare well with the lake data boxplots and support the pattern of low DOC concentrations and water colours on the west coast and elevated values in the northeastern and eastern parts of the province.

The southern Labrador basins have very similar DOC concentration boxplots (Figure 27), with median values of approximately 5.0 mg C/l and small interquartile ranges. Similar results are observed for the southwestern and central basins (03OA + 03OB + 03OC, 03PA and 03PB) while the east coast basins (03PC, 03QA + 03QB + 03QC) have slightly higher median DOC concentrations (≃ 6.0 - 7.0 mg C/l) and larger interquartile ranges. The northern Labrador basins exhibit the lowest DOC values having a median of 2.3 mg/L and an absolute range from 1.0 to 4.0 mg/L. The water colour boxplot for the Labrador basins (Figure 28) with only a few exceptions support the spatial pattern of DOC concentrations, particularly for the central, northern and east coast basins. The major discrepancies occur for the southern basins which tend to have quite variable water colours despite rather similar DOC concentrations. This is particularly noticeable for basin 02XC in southeastern Labrador which has a median water colour of 60 Hazen units and a median DOC concentration of approximately 5.0 mg C/l.

This median water colour value is the highest recorded for all the Labrador basins considered.

The DOC and water colour data for lakes in New Brunswick are extremely sparse and as such provide little indication of the spatial distribution of organic waters. In addition, many of the aquatic systems receive pulp mill effluent which will serve to increase both the water colour and DOC concentrations. The DOC boxplot for the New Brunswick river data (Figure 29) indicates that the highest median DOC concentrations (≃ 6.0 mg/L) are found to the south in basins 01AR and 01AP (01AP, 01AM, 01AL). Although basin 01AR does include some sites which are influenced by pulp mill effluent, many of the sites have high natural water colours. The other New Brunswick basins all have median DOC concentrations below 5.0 mg/L, indicating minimal influence by organic compounds. The water colour boxplots (Figure 30) for New Brunswick mimic the DOC patterns with the highest values observed in the southern part of the province.

Plate 2 presents a regional view of median hydrometric basin water colour values. This figure indicates that the basins in the southwest, the eastern shore and in northern Cape Breton tend to have surface waters with elevated water colours. Thus in these regions, natural organic acidity may be a significant contributor to the overall acidification process. The Newfoundland water colours are generally higher than those observed in Nova Scotia with only a few isolated basins having median values below 20 Hazen

8.3.1 Excess Calcium and Magnesium

Sodium and potassium concentrations in waters of Atlantic Canada are essentially derived from marine sources and thus the sum of excess calcium and magnesium can be used to indicate the potential carbonate-bicarbonate alkalinity of a basin since they are the only potential basic cations. However in any basins which have significant geological deposits of gypsum, excess calcium and magnesium concentrations will tend to overestimate the pre-acidification alkalinity.

As the excess calcium and magnesium concentration is largely dependent on geological and soil characteristics, a considerable amount of variability is to be expected when considering large scale spatial distributions. This highly variable nature is readily apparent from the four Atlantic Province histograms presented in Figure 15. In general, lakes in Nova Scotia, Newfoundland and Labrador have excess calcium and magnesium concentrations clustered around the 0.1 meq/L level with only a few sites exceeding 0.2 meq/L. Although the New Brunswick data set has a small sample size, the excess calcium and magnesium concentrations appear to be higher than those observed in the other three provinces.

Figure 16 presents the spatial distribution of excess calcium and magnesium for the Nova Scotia hydrometric basins and indicates that although individual basins exhibit large extremes, the interquartile ranges are generally in the order of 0.05 meq/L. Those basins in southern Nova Scotia and along the eastern shore which have sites situated on Devonian granites and Meguma Series bedrocks tend to have the lowest median values and the smallest interquartile ranges. The one obvious exception to this is basin 01EJ which is located in the Halifax-Dartmouth area. Although all the sites in this basin are situated on Meguma Series or Devonian granites, the median excess calcium and magnesium concentration is 0.18 meq/L and the interquartile range extends from 0.09 to 0.55 meq/L. It is unlikely that these elevated values are due solely to geology or isolated deposits of carbonate rich soils but may in fact be the result of anthropogenic induced increases in cation supply. Kerekes et. al. (1985) have observed high calcium and magnesium concentrations in two lakes near Halifax which have undergone anthropogenic disturbance of mineralized slate in the drainage basins. Thus it is probable that the elevated calcium and magnesium concentrations observed in basin 01EJ are a partial consequence of increased cation mobilization from the terrestrial watersheds due to disturbance of the mineralized slates. Basin 01DG is located to the northeast of basin 01EJ and also has a large number of sites located on Devonian granites and Meguma Series rocks. The median excess calcium and magnesium concentration for this basin is slightly higher than that observed for basin 01EJ but the interquartile range is smaller. This suggests that sites in this basin are also exhibiting some cation enrichment due to anthropogenic activities. It should also be noted that a few stations in the northeastern portion of basin 01DG are situated on

Windsor Group limestones and gypsum which will also serve to elevate the excess calcium and magnesium concentrations. The basins along the Fundy shore (01EA, 01DA, 01DB and 01DC) tend to have slightly higher excess calcium and magnesium concentrations than observed along the south and eastern shores (i.e. 01DE, EG and EH, 01EC, 01ED, 01EE and 01EN). Basin 01DC has both a high median value and a large interquartile range which is to be expected as this area represents some of the most productive agricultural land in the province. Cape Breton Island is geologically diverse and as would be expected this diversity is reflected in the variability of excess calcium and magnesium concentrations. Basin 01FD in the north has a low median excess calcium and magnesium concentration of approximately 0.02 meq/L and an interquartile range which is slightly greater than that observed for lakes along the south shore. Basin 01FJ has a median excess calcium and magnesium value of 0.08 meq/L while the value for basin 01FH is much higher at 0.15 meq/L. The median and interquartile range of basin 01FH is similar to that observed for basin 01DG near Halifax which is to be expected given the predominance of Horton and Windsor group geological formations.

Comparison of the river water quality data with the lake data is difficult as the smaller number of river stations necessitated the pooling of a larger number of hydrometric basins. Regardless of this, the river data with only a few exceptions compares well with the lake data boxplots. Hydrometric basin 01DC includes rivers from basins 01DA, 01DC and 01DD and has somewhat higher median and interquartile ranges of excess calcium and magnesium than was observed for the lakes from these areas. Many of the lakes in basins 01DC and 01DD are situated on Devonian granites while most of the river stations are located on the Cornwallis and Annapolis River systems and drain shale, sandstones and conglomerates. These areas represent some of the most productive agricultural land in Nova Scotia and thus the elevated excess calcium and magnesium concentrations are to be expected.

Figure 17 presents the spatial distribution of excess calcium and magnesium concentration for insular Newfoundland. As was apparent for Nova Scotia, the excess calcium and magnesium values within some basins can have large extremes but for the most part the interquartile ranges are approximately 0.1 meq/L. The hydrometric basins located on the Great Northern Peninsula tend to have the greatest variability of all of the basins in Newfoundland. Basin 02YA (02YA & 02YB) at the northern extreme of the Great Northern Peninsula have the highest median excess calcium and magnesium concentrations observed in Newfoundland. These basins are predominately underlain by Ordovician limestone, dolomite, sandstone, shale and quartzite formations which would explain the elevated excess calcium and magnesium concentrations. Basins 02YE and 02YH also have several sites which are situated on this Ordovician structure and as would be expected they also have either elevated median values or large interquartile ranges. The lowest excess calcium and magnesium concentrations (≃ 0.05 meq/L) were observed for stations along the south coast and those portions of the west coast not underlain by the Ordovician Table Head Formation. These basins had median values and interquartile ranges similar to those observed for the Devonian granite and Meguma Series basins on the south and eastern shores of Nova Scotia. With the exception of basins 02YA and 02YH, the highest median excess calcium and magnesium concentrations were observed for basins located in central Newfoundland and extending north to Notre Dame Bay. These basins (02YN, 02YO, 02YP) all have water quality stations which are underlain by limestone bearing formations. This zone of high concentration is bounded to the west (02YL, 02YM, 02YN) and east (02YR, 02YS, 02YQ) by basins which have moderate excess calcium and magnesium concentrations with median values of approximately 0.10 meq/L. These basins all have significant deposits of Ordovician and Carboniferous age deposits with sandstones, siltstones, shale, limestone and gypsum. The river water quality data without exception compare well with the lake data boxplots.

The southern Labrador hydrometric basins have median excess calcium and magnesium concentrations of approximately 0.08 meq/L with relatively small interquartile ranges (Figure 18). The central and western Labrador basins have boxplots similar to the southern basins, however the median values are slightly lower being close to the 0.05 meq/L level. These low excess calcium and magnesium concentrations are to be expected given the predominately granitic bedrock. The northern portion of Labrador (Basins 03ND, 03NF, 03NG) has the highest median excess calcium and magnesium concentration ($\simeq$ 0.10 meq/L) and the largest interquartile range. However from the geological map, there is no obvious geological formation which would account for the slightly elevated excess calcium and magnesium median and interquartile range. The Labrador river data agrees well with the lake data and further indicates the slightly elevated concentrations in the northern Labrador basins.

The New Brunswick lake data boxplot for excess calcium and magnesium concentration is presented in Figure 19 and reflects the more calcareous nature of the geological structure underlying much of New Brunswick. The highest median excess calcium and magnesium concentration ($\simeq$ 0.9 meq/L) was observed for basin 01AF (01AF, 01AG, 01AK) which is situated in the western part of the province and is underlain by Ordovician and Silurian age calcareous and argillaceous sedimentary rocks and limestone deposits. Basins 01AR and 01AQ are situated in the southwestern corner of New Brunswick and exhibit median values of approximately 0.18 meq/L. Lake stations in these two basins are generally underlain by Devonian age granites and Ordovician and Silurian age sedimentary rocks with minor limestone deposits. Given the small number of lake stations in New Brunswick, the river water quality data presented in Figure 20 give a better geographical overview of excess calcium and magnesium concentration. As would be expected the highest median values are observed for the basins in the northern part of the province (01AD, 01AF and 01BA). The basins are without exception underlain by Devonian, Ordovician and Silurian age formations which are rich in calcareous rocks and limestones. Basin 01BA (01BA, 01BB, 01BC, 01BE and 01BJ) has the highest median value of 1.5 meq/L followed by basins 01AF and 01AD with values of 0.80 meq/L and 0.70 meq/L respectively. The lowest median values of excess calcium and magnesium (≃ .20 meq/L) were observed for basins 01AR and 01AP. Most of the river stations located in basin 01AP (01AM, 01AN, 01AP, 01AK) are underlain by either Pennslyvanian age red to grey sandstone, conglomerate and siltstone or Mississipian sandstones, conglomerate, shale and minor limestone. As was observed for the lake data, basin 01AR had not only the lowest median excess calcium and magnesium concentration, but also the smallest interquartile range. The basins adjacent to 01AR along the south coast also had lower median values but tended to exhibit larger interquartile ranges.

Plate 1 presents an overall view of Atlantic Canada terrain sensitivity based on median lake excess calcium and magnesium concentrations. The most sensitive regions are situated in southwestern Nova Scotia and northern Cape Breton, along the south and northwest coasts of Newfoundland and in central Labrador. Those regions which are the least sensitive (i.e. having values > 0.10 meq/L) are central Nova Scotia and Newfoundland and the entire province of New Brunswick.

8.3.2 Dissolved Organic Carbon and Water Colour

As a consequence of regional geology and topography, surface waters in Atlantic Canada are characteristically coloured by natural organic acids. Thus when discussing regional acidification it is essential to assess the relative importance of natural organic acidity to the overall acidification process.

Dissolved organic carbon concentrations and water colour are the two parameters which are commonly employed as indicators of natural organic acidity. Although dissolved organic carbon measurements are more quantitative than water colour measurements and have been used by Oliver et. al. (1983) in an empirical relationship which estimates organic anion concentrations, the water colour database is more extensive. Relationships between water colour and dissolved organic carbon are good for the Nova Scotia ($r^2 = .69$), Newfoundland ($r^2 = .57$) and Labrador ($r^2 = .77$) data bases and surprisingly poor for the New Brunswick ($r^2 = .02$), suggesting that water colour data can in general be used to support the patterns observed for the DOC data. Although good linear relationships exist for three of the provinces, any individual hydrometric basin may exhibit poor water colour relationships, or relationships with vastly different slopes and intercepts. This suggests that the speciation of organic compounds must be considered in addition to the absolute concentration. Hydrometric basins in agricultural areas such as northwestern Nova Scotia and New Brunswick would be expected to have DOC concentrations elevated due to enhanced autochthonous production. In these situations DOC concentrations do not provide a reliable indication of organic acidity and are not accompanied by elevated water colours. Thus in order to properly assess the extent of natural organic acidity on a regional scale, it is essential that both DOC concentrations and water colours be considered.

Figure 21 presents the dissolved organic carbon distributions for New Brunswick, Newfoundland, Labrador and Nova Scotia respectively. The New Brunswick rivers have the lowest DOC concentrations, ranging from 1.0 to 10. mg/L with many of the values lying between 2.0 and 5.0 mg/L. The Labrador lakes span from 1.0 to 15.0 mg/L and have a rather even distribution throughout the 1.0 to 10.0 mg/L range. The Nova Scotia and insular Newfoundland data sets have the more highly organic waters and although the majority of the stations have DOC concentrations below 5.0 mg C/l both distributions are positively skewed. With the exception of the Labrador data set, the water colour histograms for the four provinces (Figure 22) show similar distribution to those observed for DOC. However, the poor agreement between DOC and water colour distributions for the Labrador lakes may be solely a consequence of the larger water colour data set.

Although DOC concentrations and water colours provide an indication of the relative importance of organic acids, it is difficult to establish levels at which organic acidity has a significant effect on the overall acidity of the system. However, given that colourless water in Atlantic Canada has 2.0 to 3.0 mg C/l and that 1 mg C/l is roughly equivalent to 10 ueq/L of organic acid (Oliver et. al., 1983) it is safe to assume that organic acidity is of minor importance in sites which have DOC concentrations less than or equal to 5.0 mg C/l. Similarly, Howell and Pollock (1986) have shown that there is little significant difference between sulphate (MTB) and sulphate (IC) concentrations for sites with water colours equal to or less than 30 Hazen units. As sulphate (MTB) appears to give a measure of organic anions in addition to actual sulphate concentration, this would suggest that organic acidity is of limited importance in sites with water colours below this level. Thus as DOC concentrations increase above 5.0 mg/L and/or water colours exceed 30 Hazen units, organic acidity will become more important to the overall acidification of the system.

Figure 23 presents the dissolved organic carbon concentration boxplots for the Nova Scotia lake data. As bog formation and organic carbon production and export are dependent on numerous biophysical features, highly variable interbasin and intrabasin DOC concentrations are to be expected. In general the highest median DOC concentrations are observed for the Meguma Series and Devonian granite dominated basins along the southwestern and eastern shores of the province. The extreme median DOC concentration (≃ 10 mg/L) was observed in basin 01FJ in southeastern Cape Breton, due primarily to a large number of highly organic systems located in Louisbourg National Park. The lowest median concentrations were observed for those basins in the northern part of the province (01DD, 01DG, 01DH) and in Cape Breton (01FD, 01FH). Although there was no overall provincial pattern there was some indication of reduced DOC concentrations for the Meguma Series and granite dominated basins near Halifax. The one exception to this is the combined data from basins 01DE, 01EG, 01EH which has a median DOC concentration similar to that of the extreme southwestern Nova Scotia basins.

The water colour boxplot for the Nova Scotia basins (Figure 24) is, with only a few exceptions, similar to the DOC boxplot. Most of the differences are for the basins along the Fundy shore which tend to have lower water colours than the measured DOC concentrations would suggest. These basins (01DB, 01DE) represent some of the best agricultural areas in the province which suggests that the measured DOC concentrations may be elevated due to increased autochthonous production rather than allochthonous organic anions. Regardless of these discrepancies, the water colour boxplots support the overall provincial pattern derived from the DOC concentrations. High median water colours are observed for most of the south and eastern shore basins which are underlain by Meguma Series and granitic rocks and a pattern of reduced water colours near Halifax is readily apparent. The DOC and water colour boxplots for Nova Scotian rivers are not shown but without exception support the geographic distributions derived from the lake data set. These data also indicate a pattern of reduced DOC concentrations and water colours in the Halifax area.

The boxplot of DOC concentrations for insular Newfoundland presented in Figure 25 indicates that the DOC data set is somewhat limited. As was apparent for Nova Scotia, interbasin and intrabasin DOC variability is rather high and is reflected by large interquartile ranges and different basin median values. The basins on the west coast of Newfoundland exhibit similar median DOC concentrations (≃ 5.0 mgC/L) but highly variable interquartile ranges. The basins with the highest median values were those situated on the Baie Verte Peninsula (02YM) and on the east coast of Newfoundland (02YS) while the Avalon Peninsula basins had the lowest median values observed. The water colour boxplot (Figure 26) gives a much better indication of the spatial pattern of organic acid influence. As was noted from the DOC boxplot, the basins on the Great Northern Peninsula have low median water colours and moderate interquartile ranges. These low median water colours extend into two basins (02YN and 02YO) in the interior of the province which comprise the Exploits River drainage. One obvious exception to this low water colour region is the combined data from basins 02YF and 02YG which has a median water colour of approximately 50 Hazen units and an interquartile range above that of the other west coast basins. The most highly coloured lakes are found in coastal basins situated in the northeastern (02YP, 02YR) and eastern (02YS, 02ZG, 02ZK) portions of the province. These basins all exhibit median water colours above 50 Hazen units and have rather large interquartile ranges. These median values are similar to those observed for the Meguma Series and granitic rocks units. Basins in the northeastern and eastern portions of the province are the most highly coloured indicating that natural organic acidity is an important consideration in this area. The Labrador sites tend to be moderately coloured in the south except for two isolated coastal basins which are dominated by highly coloured waterbodies. The northern portion of Labrador shows little organic influence. Similarly, the New Brunswick basins show little organic influence except for an isolated basin in the southwestern part of the province.

8.3.3 Excess Sulphate

Characterization of the acidic nature of precipitation has focussed on the determination of the deposition rates of hydrogen ions, nitrogen oxides and sulphates. However as concentrations of hydrogen, nitrates, nitrites and ammonia in surface waters are mediated by numerous biotic and abiotic processes, it is difficult to link export from the system to atmospheric deposition. Underwood et. al. (1986) have shown that inorganic nitrogen deposition in Nova Scotia is generally an order of magnitude lower than sulphate deposition and other Atlantic Region studies (Kerekes et al., 1982; Howell, 1986) have indicated that surface water inorganic nitrogen concentrations are generally at or below the detection limit.

This non-conservative nature of hydrogen and the inorganic nitrogen ions has led to the use of the more conservative sulphate ion as a surrogate for hydrogen ion loading in target loading estimates (MOI, 1983) and numerous acidification models (Henriksen, 1980; Thompson, 1982). Despite the fact that individual basins may have internal sulphate sources or sinks, several authors have shown linear correlations between lake sulphate concentrations and precipitation concentrations (Wright, 1983; Kelso et al, 1986). Kramer et. al. (1985) examined the relationship between atmospheric deposition and lake export of sulphate over a broad geographical area and observed significant linear relationships providing that regional differences were taken into account.

Colourimetric determination of sulphate using the methyl thymol blue (MTB) indicator is susceptable to interference by organic anions in highly coloured systems and thus overestimates the actual sulphate concentration (Cheam et. al., 1985). However the ability to achieve reasonable ion balances in coloured waters using MTB sulphate suggests that this method gives a measure of the organic anion concentration in addition to the actual sulphate concentration. Thus the MTB sulphate concentration provides an indication of the degree of acidification of a basin as a result of both anthropogenic and natural acid loading. Sulphate concentrations as measured by ion chromatography (IC) are organic anion independent and give a reliable measure of actual sulphate concentration. Thus the sulphate (IC) concentration can be used as an indicator of anthropogenic loading of strong mineral acids. Howell and Pollock (1986) have noted that waters in Atlantic Canada which have water colours below 30 Hazen units have little difference in sulphate (IC) and sulphate (MTB) concentrations. Thus in the following discussion on the spatial distribution, the sulphate (IC) will be augmented with sulphate (MTB) data from sites with water colours below 30 Hazen units.

Figure 31 presents the sea-salt corrected ion chromatograph sulphate concentration histograms for New Brunswick, Nova Scotia and insular Newfoundland. The New Brunswick lake sulphate (IC) data set is extremely limited with the majority of the values lying between 0.04 meq/L and 0.08 meq/L. The New Brunswick river sulphate (IC) data is somewhat more extensive and indicates that the majority of sites have concentrations near .100 meq/L. The histogram of sulphate (MTB) for New Brunswick lakes with water colours less than 30 Hazen units agrees with the lake sulphate (IC) data and indicates that sulphate concentrations generally lie within the 0.05 to 0.08 meq/L range.

The insular Newfoundland sulphate (IC) data are much lower than those observed for New Brunswick and approximate a normal distribution with a hypothetical mean and standard deviation of .017 and .002 respectively. The data range from a low of .005 up to a high of .035 meq/L. The histogram of sulphate (MTB) data for lakes with water colours less than 30 Hazen units is presented in Figure 32. These data are positively skewed and range from .02 to .085 meq/L with the maximum number of observations lying between .030 and .040 meq/L. It is readily apparent that the low coloured lakes in Newfoundland have much higher sulphate concentrations than the more highly coloured lakes. In fact there is little overlap between the two distributions. Thus, either the clearwater basins in Newfoundland have an additional sulphate source or the highly coloured basins have a sulphate sink. One possible explanation for elevated sulphates is that the clearwater basins are situated in regions underlain by deposits of gypsum. However when the excess calcium and magnesium concentrations are selected according to water colour, the clearwater and coloured lakes have similar distributions. Therefore it is highly unlikely that gypsum originated sulphate concentrations can explain the differences observed for the clear and coloured lakes. Another possible geological source of sulphate is from the oxidation of exposed pyrites in mineralized slates. However, as the distribution of mineralized slate is patchy and the oxidation of pyrite is dependent upon the exposure of bedrock to the atmosphere, this geological source of sulphate is unlikely to be either widespread or predominately associated with the clearwater basins.

Although it does not appear that the clearwater lakes are influenced by widespread geological sulphate sources, it is possible that the highly coloured basins are storing sulphate or are exporting reduced or organic sulphur compounds. Unfortunately mass budget studies and post sample oxidation sulphate determinations for Newfoundland lakes needed to quantify this sulphate sink are not readily available. Preliminary results of sulphate (IC) determinations on oxidized samples (Table 17) indicate that up to 50% of the sulphur in selected Newfoundland lakes may be in reduced or organic forms. Kramer et. al. (1985) have reported that lakes in Newfoundland and Labrador tended to export less sulphate than they received by wet deposition. Similarly Howell (1986) observed lower sulphate (IC) concentrations in the highly coloured lakes included in the WQB Newfoundland LRTAP Monitoring lakes. These results suggest that sulphate concentrations in coloured lakes in insular Newfoundland may not be indicative of the atmospheric sulphate deposition rate. For this reason the spatial distribution of sulphate concentration for insular Newfoundland will include only sulphate (MTB) data for lakes with low water colours.

The sulphate (IC) concentration histogram for Nova Scotia is positively skewed with values ranging from 0.01 meq/L to .23 meq/L and a maximum number of observations near the 0.05 meq/L. These values are similar to those observed for New Brunswick and are much higher than the Newfoundland levels. The histogram of sulphate concentrations for colourless lakes in Nova Scotia (Figure 32) is similar to the sulphate (IC) histogram for the coloured lakes, with the majority of the observations lying between the 0.04 meq/L to 0.06 meq/L range. Thus, unlike Newfoundland, there does not appear to be a significant amount of retention or reduction of sulphate in the highly coloured Nova Scotia lakes. Howell (1986) observed little difference between sulphate concentrations of coloured and colourless LRTAP monitoring lakes in Nova Scotia.

The Labrador lake data set does not have sulphate (IC) measurements and thus only the excess sulphate (MTB) concentration histogram for colourless lakes is presented (Figure 32). This figure indicates that the Labrador lake sulphate concentrations are considerably lower than those observed in New Brunswick and Nova Scotia and only slightly lower than the insular Newfoundland values. The majority of the clearwater lakes sampled had sulphate concentrations within the range of .018 to .04 meq/L. It is unfortunate that no comparison of clear and coloured lake sulphate concentration could be made as Kramer et. al. (1986) have noted that sulphate export from Labrador lakes is generally lower than wet sulphate deposition. Until sulphate (IC) is amassed for coloured systems in Labrador it will not be possible to investigate the potential storage or reduction of sulphate in these basins.

Figure 33 presents the hydrometric basin boxplot of excess sulphate (IC) concentrations for the province of Nova Scotia. The basins in southwestern Nova Scotia (01DA, 01EA) and along the Fundy shore (01DB, 01DC, 01DD) all exhibit similar excess sulphate boxplots having median values ranging from .052 to .060 meq/L and interquartile ranges of approximately .020 meq/L. The one exception to this is basin 01DC which has a larger interquartile range of nearly .040 meq/L. This basin includes some lakes situated in agricultural areas suggesting that geological sulphate sources may be adding to the variability. The high interquartile range of excess calcium and magnesium observed for this basin further supports the contention that a geological sulphate source such as gypsum may be influencing the variability. Despite this anomaly, the low variability and similar medians of excess sulphate concentrations are probably indicative of atmospheric deposition of sulphate. This portion of Nova Scotia, coupled with southwestern New Brunswick is considered to have the highest deposition rates of all non-point source influenced regions in Atlantic Canada. Underwood et. al. (1986) have estimated excess sulphate deposition from four western Nova Scotia precipitation stations to be 47 $meq/m^2.yr$ which, given an average annual runoff of 1.0 m/yr, is lower than the estimated lake sulphate export. However when dry deposition, which is estimated to be 20-25 percent of the wet deposition (Kerekes et. al. 1982; Underwood et. al. 1986) is included, the total sulphate deposition is similar to the estimated lake sulphate flux.

The basins along the south shore of Nova Scotia (01EC, 01ED, 01EE) show evidence of reduced lake sulphur concentrations as would be expected given the regional deposition gradient. Basins 01EC and 01ED have similar boxplots with median excess sulphates from 0.03 - 0.035 meq/L and interquartile ranges of less than 0.01 meq/L. Freedman et. al. (1985) have estimated wet deposition of excess sulphate in Kejimkujik National Park (Basin 01ED) using 1981-1983 CAPMoN data to be approximately 27 meq/m^2.yr. Once again, allowing for 20 to 25% dry deposition and using an annual average runoff of 1.0 m/yr, this estimated wet sulphate deposition agrees with the estimated excess sulphate export of 0.032 meq/L. Basin 01EE exhibits excess sulphate concentrations which are lower than the southwestern and Fundy shore basin but are slightly higher than those observed in basins 01EC and 01ED. Although this basin has a relatively narrow interquartile range, the data set does include lakes with a wide range of sulphate concentrations, having nearly an order of magnitude difference between the minimum and maximum values. This basin appears to signal the beginning of a trend of increasing median sulphate concentrations which peak around Halifax (01EJ) and then decline along the eastern shore. Along with the general increase in median values, the interquartile and absolute ranges also increase, reaching a peak for the 01EJ basin data set. Thus basins 01EF, 01DE + 01EG + 01EH, 01EJ, 01EK +

01EL + 01EM all experience median sulphate concentrations which are higher than would be expected given the LRTAP deposition gradient. Basin 01EE and 01EN seem to mark the extremes of these elevated values, having only slightly higher than expected median lake sulphate concentrations.

Several authors have indicated that local emission sources in the Halifax-Dartmouth area have served to increase both the atmospheric deposition of sulphate (Shaw, 1982; Underwood et al., 1986) and the sulphate concentrations of lakes in this region (Watt et al., 1979; Gorham et al., 1986; Machell et. al., 1983). Underwood et. al. (1986) have documented wet and dry sulphate deposition in the Halifax area of 87 $meq/m^2.yr$ while Shaw (1982) in an earlier study reported a value of 150 $meq/m^2.yr$. This value of 87 $meq/m^2.yr$ is approximately twice the deposition value apparent in the extreme southwest of the province and nearly three times greater than the Kejimkujik wet deposition value. The median sulphate concentration for the 01EJ basin lakes is .087 meq/L which, given an annual runoff of 1 m/yr, agrees with the estimated deposition rate. This median value is lower than the average sulphate concentration for nine Halifax lakes ($\bar{x}$ = 128 ueq/L) reported by Underwood et. al. (1986) but higher than the 63 ueq/L average concentration calculated by Machell et. al. (1983) for 18 lakes situated 13.5 to 76.8 km to the east of Halifax. As both Underwood _et_. _al_. and Machell _et_. _al_. have shown that lake sulphate concentrations decrease rapidly with distance from Halifax, it is probable that the discrepancy in the average or median sulphate concentrations reflects differences in the lake data sets used. Regardless of these differences, it is quite obvious that the local emissions are at least partially responsible for the increased lake sulphate concentrations.

Machell et. al. (1983) compared the sulphate concentrations of two sets of eighteen lakes situated at similar distances to the east and west of Halifax and found essentially no difference in median sulphate concentrations for the two data sets. These data are not consistent with the suggestion that the elevated sulphates to the east and west of Halifax are due entirely to local emission sources. As the predominant wind trajectories follow a southwest-northeast direction, it would be expected that sulphate deposition from local emissions would be more pronounced to the east of Halifax. The Machell et. al. data and the basin boxplots presented herein suggest a rather even distribution of elevated lake sulphate concentrations to the east, north and west of Halifax. Furthermore, Machell et. al. (1983) felt that the lake sulphate concentration versus distance from Halifax relationship that they presented as well as the equation given by Watt et al. (1979) was valid only for lakes within a 30 km radius of the point source. Thus, although local emission sulphate sources contribute to the elevated lake sulphates observed along the south and eastern shores of Nova Scotia there appear to be other significant sulphate sources which are also involved. The geology of these basins is essentially identical, being dominated by granites and bands of Meguma Series rocks. This geology indicates that gypsum derived sulphate could only influence individual basins and cannot explain the overall sulphate pattern. However, the preponderance of Meguma Series bedrock in the south and eastern shore basins would suggest that pyrite weathering may also be involved in the elevated lake sulphate concentrations. As oxidation of mineralized slates is largely dependent on exposure of the bedrock material, it would be expected that the greatest potential for pyrite weathering would center around a highly developed area such as Halifax-Dartmouth. As the distance from the urban area radiates outward, less anthropogenic disturbance of the slate bedrock is to be expected and should be reflected in a tailing off of lake sulphate concentrations. This pattern is consistent with the results of Machell et. al. (1983) and the hydrometric basin sulphate boxplots presented in this report. Basin 01DG is situated to the north of basin 01EJ and the majority of the lake stations are clustered in the extreme southern portion of the basin. This basin also has a high median sulphate concentration (.078 meq/L) with a large interquartile range (≃ .04 meq/L). Although the northern extreme of the basin is underlain by large gypsum deposits, most of the lake stations are situated on Meguma Series bedrock in an area of high anthropogenic activity and thus pyrite derived sulphates may also be an important source of sulphate. In addition, the lakes in this basin are generally within 25 km of Halifax-Dartmouth, indicating that local emission sources may also be contributing to the atmospheric sulphate deposition and consequently the lake sulphate concentrations. Basins 01EJ and 01DG both have elevated excess calcium and magnesium concentrations which coupled with the elevated sulphate concentrations would at first glance suggest that these lakes are gypsum influenced. However, Kerekes et. al. (1984) have noted that pyrite influenced basins near Halifax also exhibit elevated excess calcium and magnesium concentrations. Furthermore, many of the lakes in these two basins have no alkalinities and pH values below 5.3 indicating that they have been acidified. These data coupled with the underlying geology further support the possibility that pyrite weathering also makes a significant contribution to the acidification of lakes in the vicinity of Halifax-Dartmouth.

The basins (01DH) in the northern part of the province also exhibit relatively high excess sulphate concentration ($\simeq$ .06 meq/L) with large interquartile ranges. This portion of the province is underlain by a geological formation in which deposits of limestones and gypsum are common. In addition, this basin has high median pH and alkalinity values and the median excess calcium and magnesium concentration is higher than that of any other basin in Nova Scotia. Similar results can be observed for the basins located in the southern portion of Cape Breton Island as is indicated by basin 01FH. Lakes in this basin are generally underlain by Windsor or Horton formations of limestone and gypsum which would explain the high median sulphate, alkalinity, excess calcium and magnesium and pH values observed. Basin 01FD (01FC + 01FD) lakes are generally underlain by granitic rocks and are not under the influence of any significant local sulphate emissions and would therefore be expected to reflect the deposition gradient. The sulphate concentrations in lakes from this basin are the lowest observed in Nova Scotia, having a median value of .015 meq/L and an interquartile range of .015 meq/L. Although these sulphate concentrations agree with data presented by Underwood et. al. (1986), the predicted annual exports (runoff - 1.6 m/yr) are considerably lower than the estimated wet deposition of sulphate for eastern Nova Scotia. It should be noted that this estimated wet sulphate deposition of 38 $meq/m^2.yr$ exceeds the CAPMoN estimation of sulphate deposition for Kejimkujik given by Freedman et. al. (1985). However, as the eastern Nova Scotia deposition uses data collected from three widely spaced stations during 1977 to 1980, it is possible that this value does not adequately reflect the present sulphate deposition in northern Cape Breton Island. Despite this discrepancy, it is safe to assume that lake sulphate concentrations in remote areas of Nova Scotia which have no geological sulphate sources can adequately reflect the atmospheric deposition of sulphate.

Figure 34 presents the hydrometric boxplots for excess sulphate (MTB) concentrations in low colour lakes in insular Newfoundland and except for areas with known geological deposits indicates that there is a general west to east gradient of lake sulphate concentrations. The west coast basins all tend to have very similar median sulphate concentrations ranging from .020 - .030 meq/L. Basin 02YC (02YC + 02YD) has a slightly higher median sulphate concentration than the other basins on the Great Northern Peninsula, possibly due to some minor geological sulphate sources associated with the slates of the Ordovician Table Head Formation. Although the geology of the west coast basins is diverse, the consistent median values and quartile ranges of excess sulphate concentrations would indicate that geological sulphate sources are not significant with respect to lake sulphate concentrations. Precipitation weighted excess sulphate concentrations at Cormack (02YL) during 1984 (Vet et. al., 1986) averaged 1.1 mg/L (14 kg/ha.yr) or .022 meq/L (29.1 meq/m^2.yr) which, given an estimated annual runoff of 1.1 m/yr, agrees well with the median lake sulphate concentrations observed for the west coast hydrometric basins. It is interesting to note that these west coast Newfoundland excess sulphate concentrations are slightly higher than the values observed for lakes in the northern extreme of Cape Breton Island. It is possible that the Newfoundland lake basins are receiving additional atmospheric sulphate deposition from air masses moving to the north of Nova Scotia. An alternate explanation is that the Cape Breton Highland lakes do not reflect atmospheric deposition due to sulphate metabolism within the basin. Although there are no chemical data available which can be used to investigate this possibility, the high water colours, high elevations and large annual precipitation rates would suggest that the northern Cape Breton lake basins may have meteorological hydrological and biophysical conditions similar to those observed for Newfoundland lakes.

As was apparent for the Nova Scotia data set, the relationship between lake sulphate concentration and atmospheric sulphate deposition is often obscured by geological deposits of sulphur bearing minerals. This is particularly noticeable for the hydrometric basins in central Newfoundland (02YN, 02YO) and on the east coast (02YQ, 02YS, 02ZG) which have median sulphate concentrations exceeding those observed on the west coast. Elevated sulphate concentrations in central Newfoundland were noted by Scruton (1983) and were attributed to geological sulphate sources. All of the hydrometric basins which exhibit elevated sulphate concentrations have a large proportion of stations underlain by slates, siltstones and greywacke, suggesting that pyritic originated sulphates may be involved. Scruton (1983) came to a similar conclusion and observed that elevated iron concentrations corresponded to the elevated sulphates observed for sites located in the Exploits River Valley (Basins 02YN and 02YO). The basins located on the south coast are essentially underlain by granitic material and have very little anthropogenic acitivity and thus there should be minimal geological sulphate contribution to the lake sulphate concentrations. Basins 02ZD and 02ZF have median sulphate concentrations of .017 meq/L which are approximately .010 meq/L lower than those observed for the west coast basins. Precipitation weighted excess sulphate concentrations measured at Baie D'Espoir (Basin 02ZE) in 1984 averaged 0.79 mg/L (13.1 kg/ha.yr) or .016 meq/L (27.2 meq/m^2.yr). Given an annual runoff of approximately 1.3 m/yr, the estimated lake excess sulphate export appears to be slightly lower than the atmospheric deposition. Basin 02YM (02YG, 02YM, 02YP) which is situated in north-central Newfoundland also appears to follow the west-east deposition gradient. This basin group is comprised of lakes which are generally underlain by granitic rocks or Silurian deposits of sandstone, conglomerate and acidic to mafic volcanic rocks and has a median sulphate concentration of approximately 0.018 meq/L.

Scruton (1983) also concluded that Newfoundland lake sulphate concentrations supported the west to east deposition gradient. However the sulphate contour map generated from the National Inventory data has some obvious differences from the data presented in this report. Scruton observed elevated excess sulphate (MTB) concentrations in lakes in the southwestern portion of the province whereas the hydrometric basin boxplot (Figure 35) indicates an excess sulphate (MTB) median concentration and interquartile range similar to that of the other west coast basins. A possible explanation for this discrepancy is that the National Inventory data set included lakes located in the Flat Bay area which are underlain by Carboniferous age gypsum deposits (Scruton, pers. comm.).

Lake and river excess sulphate (IC) concentrations in New Brunswick exhibit little spatial variability, with all basins having high median values. The lowest median value of .063 meq/L is observed for lakes in basin 01AQ in southwestern New Brunswick, a value which is among the highest recorded for any hydrometric basin in the other provinces. Due to the limited number of lake stations in New Brunswick, a better feeling of the spatial distribution of excess sulphate (IC) concentration can be obtained from the river data set (Figure 36). The western basins all have similar median values ranging from .090 to .11 meq/L and may be reflecting the higher deposition rate expected for New Brunswick. However, many of the basins also have large interquartile ranges, indicating that other sources may be contributing to the sulphate concentrations. Given the geology of the province coupled with the agricultural and industrial activities, it is to be expected that non-LRTAP sources may be significant contributors to overall lake and river sulphate concentrations. Because of this it is not reasonable to assume that excess sulphate concentrations give an adequate reflection of the sulphate deposition gradient for the province of New Brunswick.

The Labrador lakes have no sulphate (IC) measurements and thus it is necessary to use the sulphate (MTB) data for colourless sites to discuss the spatial distribution. The southern basins of Labrador (Figure 37) indicate a slight west to east gradient in median sulphate concentrations with the most southeasterly basin (02XB) having a median and interquartile range similar to that observed for the great Northern Peninsula. The western, central and northern Labrador basins indicate that the sulphate distribution also has a strong south - north pattern. Thus the highest median excess sulphate concentrations were observed in the southwestern Labrador basins (03OA, 02VC, 02XA) while the central and east coast hydrometric basins (03PA, 03PC, 03QA, 02XB) had approximately .010 meq/L lower values. The lakes situated in the northern portion of Labrador (03NG) had a median excess sulphate concentration of less than .02 meq/L which is similar to the values observed for the south coast of insular Newfoundland and the northern extreme of Cape Breton Island. The Labrador excess sulphate data shows limited variability, with all the basins having similar interquartile ranges of approximately .020 meq/L. This small basin variability suggests that geological sulphate sources are of minor consequence and therefore lake and river sulphate concentrations should reflect atmospheric sulphate deposition. Although there is limited precipitation data for Labrador, the CAPMoN stations at Goose Bay (01OE) had a 1984 precipitation weighted excess sulphate concentration of 0.85 mg/L (7.5 kg/ha.yr) (Vet et. al., 1986). This value equates to a wet sulphate concentration of .018 meq/L (15.6 meq/m^2.yr) which when corrected for 20 to 25% dry deposition gives an estimated sulphate deposition value of approximately .022 meq/L (19 meq/m^2.yr). Median lake sulphate concentration in the 03OA basin (03OA, 03OB, 03OC, 03OE) is .030 meq/L while the other basins in the Goose Bay area (03PA, 03PC, 03QA) have median excess sulphates of approximately .025 meq/L. Given an estimated annual runoff of .6-.7 m/yr, these values agree rather well with the Goose Bay CAPMoN precipitation excess sulphate deposition, supporting the contention that the Labrador lake excess sulphate data reflect the atmospheric deposition rate.

Plate 3 presents an overall view of excess sulphate (IC) concentrations observed in Atlantic Canada. Although the previous discussion has indicated that the regional excess lake sulphate concentrations reflect the deposition gradient, the atmospheric deposition rate can only address potential acidification when discussed in relation to terrain sensitivity. The highest excess lake sulphate concentrations of LRTAP origin are observed in western New Brunswick and southwestern Nova Scotia. The excess calcium and magnesium concentrations in New Brunswick are among the highest in the region and indicate high potential basin buffering capacity. The southwestern Nova Scotia lakes have extremely low excess calcium and magnesium concentrations which coupled with the high apparent sulphate loads indicate that these basins have a high potential for acidification. The northern Cape Breton lakes have both the lowest sulphate concentrations (i.e. sulphate deposition) and excess calcium and magnesium concentrations observed in Nova Scotia. The similar equivalent concentrations of these two parameters suggests that sites in this basin are in danger of losing their innate bicarbonate alkalinities even under the present low sulphate loading scenario. Similar observations can be made for the Great Northern Peninsula and southcoast basins of Newfoundland. Although the sulphate deposition in insular Newfoundland is much lower than observed in southwestern Nova Scotia, the terrain sensitivity is generally much higher. Thus these basins, particularly basins 01ZB and 01ZC along the south coast of Newfoundland have a high potential for acidification. In Labrador, given the present deposition rate, potential acidification appears to be restricted to the extreme southwest basins. This region exhibits the highest lake sulphate concentrations coupled with the lowest excess calcium and magnesium concentration observed in Labrador.

While sulphate (IC) concentrations can be used to provide an indication of strong mineral acid loading, sulphate (MTB) concentrations give an approximation of combined mineral and organic loads and may represent the total system acid load (Howell, 1986; Thompson, 1986). Figure 38 presents the hydrometric basin excess sulphate (MTB) concentrations for some of the Nova Scotia basins. Comparison with the sulphate (IC) boxplots indicates that there are two hydrometric basins which appear to be strongly influenced by natural organic acids. Basin 01ED has median sulphate (IC) and median sulphate (MTB) concentrations of .032 meq/L and .055 meq/L, indicating essentially equal contribution of mineral and organic acids to the overall acidification of systems in this basin. Basin 01FD also has a large difference between sulphate (IC) and sulphate (MTB) concentrations, having median values of .017 meq/L and .040 meq/L. This indicates that mineral and organic acids in these basins both make significant contributions to the acidification process. As a consequence of the high terrain sensitivity of both the 01ED and 01FD basins it appears that the present sulphate loads in many lakes would be sufficient to overcome the innate bicarbonate buffering potential. When coupled with the natural organic acid loads, the potential for widespread bicarbonate alkalinity loss and reduced pH values increases. From Figure 24 it is apparent that these two basins have elevated median water colours, indicating that water colour can be used to indicate potential organic acid contribution to the overall acidification process. Using the water colour spatial distribution, the basins located in southwestern and northeastern Nova Scotia would be expected to show the largest degree of acidification observed in Nova Scotia due to the combined loads of anthropogenic mineral acids and natural organic acids. The sulphate (MTB) boxplot for the Newfoundland lakes is presented in Figure 35 and indicates that most of the Newfoundland basins have some natural organic acid contribution. For the majority of the basins the organic acids account for approximately .005 to .010 meq/L which is a small percentage of the observed mineral acid load. However, the basins along the south coast and two central Newfoundland basins (02YK and 02YM) have nearly equal mineral and organic acid contributions. As was noted for Nova Scotia, the south coast basins have the lowest innate bicarbonate buffering observed in Newfoundland and thus the combined mineral and organic acid loads suggest that these basins are at the greatest risk of potential acidification. Unlike Nova Scotia, the relationship between organic acid contribution and basin water colour is not particularly consistent. Although all the basins which have significant organic influence are highly coloured, many other coloured basins exhibit only moderate differences between the sulphate (MTB) boxplot and the colourless lake sulphate (MTB) figure. This is probably an artifact caused by the limited number of sites in these basins which have measurements for all three parameters.

The sulphate (MTB) values for the Labrador basins are presented in Figure 39. This figure, when compared with the sulphate (MTB) boxplots for colourless sites, indicates that the natural organic acid load is minor when compared to the excess sulphate concentration. The most highly influenced basins are located in the southern part of the province and have an organic acid concentration of approximately .010 meq/L. The New Brunswick river excess sulphate (MTB) boxplots (Figure 40) are essentially identical to those given for excess sulphate (IC), which indicates that as was apparent for Labrador the New Brunswick lakes generally have insignificant organic acid loads.

8.3.4 Alkalinity

The carbonate-bicarbonate alkalinity plays a major role in the governing of the pH of most natural surface waters. Machell et. al. (1985) have shown a bimodal pH distribution for lakes in Nova Scotia with few sites at 5.4 and modes at 5.0 and 6.0. This indicates that lakes in this region have pH values under the control of both the bicarbonate system and some other buffering system. In sites which have no carbonate-bicarbonate alkalinity and pH values less than 5.6, metals such as aluminium and weak organic acids with their anions may also be involved in buffering the system. In fact, these systems may be strongly buffered at pH levels lower than 5.6. Although the extent of buffering by metals and weak acid anions cannot be quantified, the small pH variability observed for many highly coloured waters (Kerekes et al., 1986) indicates the strength of these buffering systems. This implies that the lack of measured total alkalinity can be employed as an indication of previous acidification but not as a direct measure of sensitivity or buffering capacity. In fact, it is probable that sites with low positive alkalinity and pH values around 5.6 are more sensitive to further acidification than low pH, negative alkalinity sites.

Figure 41 presents the total alkalinity (total & Gran alkalinity determinations) distributions for the four provinces and indicates that waters in Atlantic Canada have in general, extremely low alkalinity concentrations. The Nova Scotia and Newfoundland data sets have similar distributions with the maxima near to the 0.0 alkalinity level. A similar distribution is apparent for New Brunswick although it is somewhat more positively skewed. It should be noted that the small number of lakes and the fact that they are predominately located in two basins in southern New Brunswick may account for the high proportion of low alkalinity sites. If the total alkalinity distribution for the New Brunswick rivers is considered (Figure 42) it becomes readily apparent that the alkalinities are higher than those observed in either Nova Scotia or Newfoundland. The Labrador alkalinities are also low but there are few sites which have no bicarbonate alkalinity.

The total alkalinity boxplot for the Nova Scotia hydrometric basins is presented in Figure 43. The highest alkalinities were observed in basins 01DH, 01FH and 01FJ and as would be expected corresponded to high excess calcium and magnesium concentrations. These basins also have excess sulphate concentrations exceeding those expected from atmospheric deposition which, given the predominate limestone and shale geological structures, are apparently a consequence of gypsum deposits. The rather good agreement between excess calcium and magnesium and total alkalinity concentrations for these basins further supports the conclusion that the elevated sulphates are the result of non-acidic geological sulphate sources. The two basins near Halifax are also interesting in that they have high median excess calcium and magnesium (≃ .19 meq/L) concentrations and greatly reduced median total alkalinities (≃ .035 meq/L). Thus it appears that these two basins have experienced considerable acidification, presumably due to the combined effects of LRTAP, local emissions and natural acid drainage. The basins in southwestern Nova Scotia all have extremely low total alkalinities with median values ranging from .005 to .05 meq/L. Similar values are observed for several of the eastern shore basins and basin 01FD in northern Cape Breton. The lowest median values (≃ .005 meq/L) were observed for basins 01EC and 01ED in southwestern Nova Scotia, basins 01EK, 01EN and 01EO along the eastern shore and basins 01FD in Cape Breton. Basins 01EC, 01ED, 01EN and 01FD all have low innate buffering potential and thus the present sulphate load in addition to the organic acid load has resulted in extremely low alkalinities. Basin 01EK has slightly higher excess calcium and magnesium concentration but due to the high mineral acid load near Halifax, the total alkalinity values are similar to those in the geologically more sensitive basins. The fact that basins 01EC, 01ED and 01EK have numerous sites which have lost all of their bicarbonate alkalinity, indicates the severity of acidification.

In order to adequately address the extent of alkalinity loss in a basin it is often better to consider the alkalinity deficit (Ca + Mg - Alk) or the total alkalinity: excess calcium and magnesium ratio. Each of these calculated values provides useful information but they both have some shortcomings. The alkalinity deficit boxplot for the Nova Scotia lakes is presented in Figure 44. Alkalinity deficits are useful as they give an estimate of the alkalinity equivalents lost due to acidification. However, this deficit value has some inherent problems which make interpretation difficult. Any gypsum influenced waters will have excess calcium and magnesium concentrations elevated relative to total alkalinity and thus will indicate a false alkalinity loss. The influence of gypsum will similarly affect the total alkalinity to excess calcium and magnesium ratio. An additional problem with the alkalinity deficit is that continued acidification of basins which have lost their original bicarbonate alkalinity will not be adequately reflected by the alkalinity deficit, particularly as other buffering systems become important. Thus basins which have low excess calcium and magnesium concentrations will tend to have lower alkalinity deficits than expected.

Basins 01DA and 01EA in southwestern Nova Scotia have similar alkalinity deficits of approximately .05 meq/L, as would be expected given their similar sulphate concentrations and DOC values. The basins along the Fundy coast (01DB, 01DD) tend to have lower alkalinity deficits, presumably in response to slightly lower sulphate deposition and less organic acid contribution. Basin 01DC is anomalous in that it has a lower alkalinity loss than the extreme southwestern basins despite similar water colours and sulphate concentrations. However, the high interquartile ranges of excess calcium and magnesium, excess sulphate, water colour and alkalinity deficit suggest that the diverse geology underlying the sites in this basin in addition to anthropogenic activities such as agriculture may be the cause of the lower than expected alkalinity deficit. Basins 01EC and 01ED have slightly lower alkalinity deficits which is to be expected given the lower deposition. However, as the excess calcium and magnesium concentration are extremely low and these basins have median alkalinities at or below zero, it is probable that the predicted deficits are biased low. As would be expected, the alkalinity deficits increase as Halifax is approached with high median values and large interquartile ranges observed for basins 01DG, 01EJ and 01EK in the immediate vicinity of Halifax-Dartmouth. Basin 01EN on the eastern shore and basin 01FD in northern Cape Breton both exhibit alkalinity deficits similar to those of basins 01EC and 01ED and are also probably biased low. On the other hand basin 01FH and 01FJ which are underlain by gypsum bearing formations have alkalinity deficits of .05 meq/L. These values probably reflect an overestimation of preacidification alkalinity rather than the extent of acidification.

Although it is useful to have an estimate of the equivalent alkalinity loss in a basin, any given deficit will have more serious consequences in basins with low preacidification alkalinities. For this reason, the alkalinity to excess calcium and magnesium ratio often provides a better indication of the impact of basin acidification (Figure 45). Basin 01DA has the lowest median ratio of the extreme southwest and Fundy shore basins, indicating that approximately 60% of the original alkalinity has been lost. The fact that this basin has higher alkalinity deficits and similar water colours to the other basins would suggest that this result is due to elevated mineral acid loading. This is supported by the slightly greater median sulphate concentration observed for basin 01DA lakes. By far the most serious acidification effects in southwestern Nova Scotia are in basins 01EC and 01ED which have lost on average 75-80 percent of their original alkalinity. The interquartile range for 01ED overlaps the 0. ratio line indicating that a significant number of lakes in this basin have lost all bicarbonate alkalinity. Similar observations can be made for the highly sensitive 01FD basin in Cape Breton. The basins surrounding Halifax-Dartmouth (01DE, 01DG, 01EJ and 01EK) all have median alkalinity to excess calcium and magnesium ratios which are lower than 0.4, indicating that more than 60% of the original bicarbonate alkalinity has been lost. Basin 01EK to the east of Halifax shows the most extreme evidence of acidification with a median ratio near to the 0.0 level. These low ratios reflect the relatively high terrain sensitivity and the high mineral acid loading due to the combined effects of LRTAP, point source loading and pyrite weathering. Basin 01EJ has an extremely high interquartile range, with many of the sites exceeding unity. These anomalous values may be the result of analytical errors or overestimation of marine origin calcium and magnesium due to elevated chloride concentrations from road salting. However, regardless of these problems, the median alkalinity to calcium and magnesium ratio indicates that many sites near Halifax have experienced considerable alkalinity losses.

The total alkalinity boxplots for the Newfoundland basins (Figure 46) are rather variable indicating the geological inhomogenity of the province. The highest total alkalinities are observed in the extreme northern portion of the Great Northern Peninsula (Basins 02YA and 02YB) and correspond to the highest excess calcium and magnesium concentrations recorded for the province. Basin 02YH also has an elevated median and interquartile range of both total alkalinity and excess calcium and magnesium while basin 02YE has higher interquartile ranges than observed for the other insular Newfoundland basins. These basins all have some stations underlain by the Ordovician age Table Head Formation of limestone and dolomite. Despite this, several of the Great Northern Peninsula basins (02YC, 02YE and 02YF) have median total alkalinities of approximately .025 meq/L and thus are sensitive to additional acidification. In addition, the in-lake LRTAP originated sulphate concentrations are highest for basins on the west coast and thus low alkalinity basins in this area are at the greatest potential risk from further acidification. Extremely low median total alkalinity concentrations are also apparent for the granite dominated south coast basins, particularly basin 02ZC. The basins in central and eastern insular Newfoundland generally have higher median and interquartile ranges of total alkalinity, reflecting the diverse geological structures underlying these areas.

The highest median alkalinity deficit ($\simeq$ .05 meq/L) is found for basin 02YA on the Great Northern Peninsula (Figure 47). This is higher than expected given the median sulphate concentration of .025 meq/L and low median water colour observed for lakes in this basin. However, due to the high alkalinity and excess calcium an magnesium concentrations observed for the 02YA lakes, smal analytical errors may have resulted in overestimated alkalinit deficits. The other Great Northern Peninsula basins all hav alkalinity deficits in the .025 to .030 meq/L range and agre rather well with the median sulphate concentrations. The centra and eastern basins tend to have slightly greater alkalinit deficits corresponding to areas of higher geological sulphates an water colours. The south coast basins show a west to east gradien in alkalinity deficit which parallels the excess lake sulphat concentration and water colour patterns and the expected depositio gradient rather well. The lowest median alkalinity defici observed for insular Newfoundland was .020 meq/L for basin 02ZF o the south coast.

The alkalinity to excess calcium and magnesium ratios (Figur 48) indicate that although basin 01YA has the highest alkalinit deficit, it has lost only a small percentage of its origina alkalinity. The lowest median ratios are observed for basins 02Y and 02ZC, which have values of .15 and .20 respectively. Thi indicates that on average, sites in these basins have lost at leas 80% of the pre-acidification alkalinity. Although basin 02YF ha excess sulphate concentrations and terrestrial sensitivity simila to the basins 02YC and 02YE, the sites in this basin tend to b more highly coloured. Thus it appears that organic acidity i conjunction with strong mineral acidity has resulted in th apparent alkalinity loss in this basin. Basin 02YC and 02YE als exhibit significant alkalinity losses, having alkalinity to excess calcium and magnesium ratios less than 0.4. As sites in these two basins are only moderately coloured, the 60% reduction in alkalinity appears to be the result of the present atmospheric deposition loading. Many of the central and east coast Newfoundland basins also have rather low ratios (02YL, 02YM, 02YQ, 02YR and 02YG); however these basins have either elevated water colours or elevated sulphates due to geological sources. As was the case for most of the Great Northern Peninsula basins, the lakes in the south coast basins appear to reflect the atmospheric deposition gradient and thus the alkalinity to excess calcium and magnesium ratio should not be affected by geological sulphate sources such as pyrites or gypsum. The lowest median ratio for the south coast is 0.2 observed for the 01ZC basin. This basin has extremely high terrain sensitivity and despite the modest atmospheric mineral acid and organic acid loads, lakes in this area have lost on average 80% of the preacidification alkalinity. Although the basins to the east of 01ZC show similar terrain sensitivity, the lower sulphate concentrations (i.e. lower deposition) have resulted in less severe alkalinity losses in the order of 50%. The alkalinity data is consistent with the spatial distribution of the other parameters considered and indicates that the south and west coast basins are both the most sensitive and the most highly acidified basins in insular Newfoundland. It is interesting to note that unlike Nova Scotia, none of the Newfoundland basins have a large percentage of sites with alkalinity to excess calcium and magnesium ratios equal to or below zero. This suggests that in general the present combined loading of natural organic acids and LRTAP originated mineral acids is not sufficient to completely overcome the bicarbonate alkalinity. However it should be noted that because of the extremely sensitive nature of the west and south coast basins, a small increase in atmospheric load of approximately .01-.02 meq/L could result in a significant increase in the number of lakes with no bicarbonate alkalinity.

Total alkalinities in the southern Labrador basins are higher than those observed on the Great Northern Peninsula with median values ranging from 0.025 to 0.04 meq/L (Figure 49). The median alkalinity deficits for the basins range from .025 to .030 meq/L and increase from the west to east. Although the slightly higher alkalinity loss for the southeast coast basin (02XC) is the opposite of what is to be expected from the sulphate gradient, this pattern agrees with the water colour distribution. The alkalinity to excess calcium and magnesium ratio for these basins tend to be high with median values generally exceeding 0.5. The lowest median ratio of 0.40 was observed for basin 02XC presumably due to greater involvement of organic acidity. The total alkalinities of the central, western and northern Labrador basins have median values ranging from a low of .025 meq/L in basin 03PC up to 0.08 meq/L for basin 03NG to the north. The total alkalinity median values and interquartile ranges for the eastern and central Labrador basins (03OA, 03PA, 03QA) are extremely similar with median values near .05 meq/L. These total alkalinity values are slightly higher than those observed for the southern Labrador basins. Basin 03PC on the east coast has the lowest alkalinity of all the Labrador basins with a median value of 0.02 meq/L. However, this basin also has high water colours, suggesting that organic acids are important contributors to the acidification of lakes in this basin. Alkalinity deficits are low for all of these basins, having median values ranging from .015 to .025 meq/L (Figure 50). These deficits are slightly lower than the values recorded for the southern basins as would be expected given that the sulphate gradient has a south to north orientation. Although there are some basins which have appreciable median water colours and thus organic acids may contribute to the overall acidification process, the lake sulphate concentrations tend to agree with the observed alkalinity deficits. The alkalinity to excess calcium and magnesium ratios for the central and northern Labrador basins are on average greater than 0.6, indicating that only a small percentage of the original bicarbonate alkalinity has been lost to acidification (Figure 51). These data show that even though some areas of Labrador are geologically sensitive to acidification, the present LRTAP deposition rate combined with the organic acid loads is insufficient to result in extreme acidification.

Although eastern New Brunswick receives as much or more atmospheric deposition of acidic compounds than Nova Scotia, the province also has much lower terrain sensitivity. Total alkalinities are high, with all basins having median values exceeding .10 meq/L (Figure 52). The lowest values are observed for the southern basins 01AR and 01AQ and the Miramichi river basin (01BQ). The alkalinity deficits for the New Brunswick rivers are rather consistent with median values ranging from .07 to .15 meq/L (Figure 53). These deficits tend to agree with the observed excess sulphate concentrations of .10 meq/L indicating that this province has experienced the greatest loss of alkalinity due to atmospheric deposition. However, the alkalinity to excess calcium and magnesium ratios are generally high which implies that only a small percentage of the bicarbonate alkalinity has been lost to acidification (Figure 54). Two New Brunswick basins (01AP, 01BQ) exhibit reduced median ratios (≃ .5) and high interquartile ranges which indicates that some of the sites have lost much of the available bicarbonate alkalinity.

Plate 4 presents an overall view of the total bicarbonate alkalinity spatial distribution for Atlantic Canada. The lowest alkalinities are observed in southwestern Nova Scotia, along the eastern shore and the tip of Cape Breton. Extremely low values are also observed on the Great Northern Peninsula and along the south coast of Newfoundland. These are the areas where given the present loading scenario the potential of acidification is the greatest. While some of the low alkalinities may be a consequence of point source loadings or pyrite weathering (i.e. sites around Halifax), the others result from the combined effects of LRTAP and natural organic acidity. The spatial distribution of the alkalinity to excess calcium and magnesium ratios for the Atlantic Canada hydrometric basins is presented in Plate 5. The Nova Scotia basins underlain by granite and Meguma Series rocks have in general lost the greatest percentage of their original alkalinity. Although the alkalinity losses for the eastern shore basins involve pyrite weathering and point source acid loading, the southwestern and Cape Breton Island basins have experienced alkalinity losses due partially to LRTAP. The Newfoundland basins which are the most severly impacted by LRTAP are located on the Great Northern Peninsula and the southwestern portion of the province. Although most of the other basins have lost some of their original bicarbonate alkalinities, the present acid loads have not resulted in extensive acidification.

8.3.5 pH

Figure 55 presents the relationship between alkalinity and pH for selected southwestern Nova Scotia lakes and indicates that the titration equivalence point occurs through a pH range of 5.3-5.6. Based on this, a pH value of 5.3 will be employed to indicate the complete loss of the bicarbonate buffering system.

Histograms of lake pH values for Labrador, New Brunswick, Newfoundland and Nova Scotia are presented in Figure 56. Labrador and New Brunswick (rivers) have pH distributions with ranges of approximately 3. pH units with the majority of the data above pH 6.0. A small percentage of these data are below 5.3, indicating that the lakes in these two regions are generally under the control of the carbonate-bicarbonate buffering system. The Newfoundland pH values have a range similar to that observed for Labrador and New Brunswick but the distribution is more negatively skewed. The distribution for Nova Scotia has a pH range from 4.0 to 8.0 with the majority of data lying between 5.0 and 6.0. There are a large number of sites with pH values below 5.3 indicating the loss of the carbonate- bicarbonate buffering system. There is a slight indication of a bimodal pH distribution for Nova Scotia with a minimum of observations slightly above the bicarbonate endpoint.

Figure 57 presents the cumulative probability plots of observed pH for the four lake data sets and indicate that the pH data are normally distributed. Using these figures, it is apparent that .5, 0, 9 and 30 percent of the sites in Labrador, New Brunswick, Newfoundland and Nova Scotia respectively have pH values less than or equal to 5.3. Using an acid-lake cut-off point of 5.0, 15% and 1% of Nova Scotia and Newfoundland stations respectively have pH values below 5.0.

Figure 58 presents the pH boxplots for the Nova Scotia hydrometric basins. The median pH values for the province range from 4.6 (01EC) to 6.4 (01DH) with most of the basins having interquartile ranges of less than 1.0 pH unit. One obvious exception to this is basin 01EJ which has an interquartile range spanning 1.5 pH units and the lowest lake pH (4.1) of the entire Nova Scotia data set. High variability has been noted for most of the parameters in this basin and appears to be a consequence of variable acidification due to point source loading, pyrite weathering and LRTAP. The Nova Scotian pH distribution appears to follow the alkalinity and alkalinity to excess calcium and magnesium ratio spatial patterns rather well. The southwestern Nova Scotia basins (01DA, 01EA) have lost at least 60% of their pre-acidification bicarbonate alkalinity and have median pH values ($\simeq$ 5.7) close to the bicarbonate endpoint and total alkalinities below .02 meq/L. This makes these two hydrometric basins extremely sensitive as a small increase in either anthropogenic mineral acid or natural organic acid loading could result in a complete loss of bicarbonate alkalinity and a significant decrease in pH. At present there appears to be a rather equal contribution of LRTAP and natural acidity to the overall acidification of these two basins. Basin 01EC has the lowest median pH of all the Nova Scotia basins with all of the sites having pH values below 5.5. This basin has lost more than 80% of its original bicarbonate alkalinity and has a median alkalinity near 0.0. Basin 01ED which is adjacent to 01EC has a similar alkalinity and alkalinity to excess calcium and magnesium distribution but has slightly higher pH values. Although the excess sulphate (IC) concentration of lakes in Basin 01EC is slightly greater than that observed for Basin 01ED, the converse is apparent for water colour. However, many of the extremely low pH sites in basin 01EC have no water colour or DOC measurements and thus the importance of organic acidity in acidification of lakes in this basin may be underestimated. Thus it appears that 01EC and 01ED are the most severely acidified basins in southwest Nova Scotia due to the combined effects of natural organic acidity and LRTAP originated mineral acidity. The south shore basins closer to Halifax (01EE, 01EF) tend to have higher pH values with medians near to (01EE) or above (01EF) the bicarbonate equivalence point. Although these basins have higher sulphate concentrations due presumably to the influence of pyrite weathering, the absence of organic acidity and the higher innate buffering capacity has mitigated the higher mineral acid loads. However it should be noted that basins 01EE and 01EF have lost 60% and 50% of their preacidification alkalinity respectively and have median bicarbonate alkalinities which are less than .04 meq/L. Thus as was noted for basins 01DA and 01EA, these basins (particularily 01EE) are extremely sensitive to any additional acid loads. Histograms of pH for these four southwestern Nova Scotia basins (Figure 59) all have a characteristic bimodal distribution indicating a mixture of bicarbonate system buffered lakes and acidified lakes. The basins around Halifax have different pH distributions depending on terrain sensitivity and the relative contributions of the various strong mineral acid loads (Figure 60). Basins 01DE and 01EK both have high terrain sensitivities and high acid loads and as would be expected have median pH values well below the bicarbonate equivalence point. This is particularily pronounced for sites in basin 01EK which with few exceptions have pH values below 5.0. Basins 01DG and 01EJ have somewhat different pH distributions than 01DE and 01EK. Although basin 01DG receives a high mineral acid load, the low terrain sensitivity of this basin is sufficient to maintain most lake pH values well above 5.3. Basin 01EJ has a slightly higher median excess sulphate load and a similar terrain sensitivity which results in a lower median pH value than was observed for basin 01DG. Although this median value is near the bicarbonate equivalence point, the pH histogram indicates that the sites in this basin have an unusual bimodal distribution with most of the values clustering around 4.8 and 6.8 pH values. This distribution suggests that these lakes are either strongly acidified or only slightly acidified which supports the contention that the point source emissions and pyrite weathering are the major sources of acid loading in this basin. The median pH values of the eastern shore basins are near to 5.3 indicating that many of these sites have also lost their bicarbonate buffering capacity. However as the sulphate concentrations are higher than expected from LRTAP it is possible that these basins are also influenced by pyrites. In addition these basins have appreciable water colours indicating that natural organic acidity is involved. Basin 01FD on Cape Breton comprises a highly sensitive area receiving modest atmospheric sulphate loads. However, this sulphate load coupled with high natural organic acidity has resulted in a loss of more than 80% of the original alkalinity and the median alkalinity concentration is now less than .02 meq/L. The median pH for this basin is 5.3 and the pH boxplot indicates that a large percentage of sites in this basin have lost their bicarbonate alkalinity due to the combined effects of natural organic acidity and LRTAP originated mineral acidity.

As Newfoundland receives lower atmospheric deposition than Nova Scotia, higher lake pH values are to be expected. This is readily apparent from the pH boxplot (Figure 61) which indicates that only one Newfoundland hydrometric basin has a median pH close to 5.3. Basin 02YF which is situated on the east coast of the Great Northern Peninsula has lost more than 80% of the original alkalinity and has a median total alkalinity concentration of less than .02 meq/L. Although the atmospheric sulphate loading is moderate (≃ .03 meq/L), the addition of a high organic acid load is sufficient to result in loss of alkalinity and pH reduction of a large percentage of lakes in this basin. Basin 02YC to the north of 02YF also shows some evidence of acidification having a median pH of 5.9 and a lower quartile pH of 5.3. Lakes in this basin have slightly higher excess sulphate concentrations than those in 02YE but the water colours are lower. Although this lower acid load is still sufficient to result in more than 40% loss of original alkalinity, many of the sites in this basin still have enough bicarbonate alkalinity to retain pH levels above 5.3. Basin 02ZC located on the southwestern coast of Newfoundland has a median pH value close to the bicarbonate endpoint with many sites having lost all bicarbonate alkalinity. The alkalinity to excess calcium ratio indicates that on average lakes in this basin have lost more than 60% of their original bicarbonate alkalinity and have alkalinity concentrations less than .02 meq/L. As was apparent for basin 02YC, the atmospheric sulphate loads are similar to those observed for basin 02YF but the natural organic acidity is somewhat lower. Two east coast basins (02YR, 02ZG) have also experienced significant alkalinity losses and have several sites with reduced pH values and no bicarbonate alkalinities. These basins have elevated sulphate concentrations due to geological sources as well as high water colours and thus the acidification of these basins can be explained by the combined natural loads of mineral and organic acids. The other Newfoundland basins have a majority of their sites with pH values above 5.3 and although they have experienced varying degrees of alkalinity loss, the present acid loads appear to be insufficient to cause major pH reductions.

The Labrador basins (Figure 62) have pH distributions similar to the central Newfoundland basins and without exception had lower quartile values above 5.3. All basins had median pH values above 6.0 and interquartile ranges of less than 1.0 pH unit. The basins in southern Labrador (02XA, 02XB, 02XC) and 03PC on the east coast had the greatest frequency of sites with pH values less than 6.0 presumably in response to the combined natural organic and anthropogenic mineral acid loads. However it is safe to say that all the Labrador lakes have experienced only moderate alkalinity losses and that the present atmospheric loading scenario has had minimal effect on lake pH.

The New Brunswick basins exhibit little pH response despite the fact that the province is receiving the highest atmospheric deposition in the region. The New Brunswick river basin median pH values are all greater than 6.5 and have lower quartiles above 6.0 (Figure 63). Of all the basins the lowest pH values are observed in basin 01AP in the southern portion of the province. The New Brunswick lake basin boxplot shows some lower pH values with basin 01AQ having a median value of 5.8 and lower and upper quartiles of 5.6 and 6.3 respectively. These two basins both are situated in southern New Brunswick and have shown the greatest percent loss of original alkalinity. Although these basins appear to be the most sensitive of the New Brunswick sites, there is enough innate buffering capacity to mitigate the effects of the present relatively high atmospheric deposition rates.

Plate 6 presents the overall view of hydrometric basin pH for Atlantic Canada. This figure indicates that the Nova Scotian aquatic systems generally have the lowest pH values with many basins having median values below the bicarbonate equivalence point. These low pH values are particularily apparent for basins underlain by granitic or Meguma Series rocks which are receiving a combination of natural and anthropogenic acids loads. The southwestern Nova Scotia and the northern Cape Breton basins have low pH values which can in part be directly attributed to LRTAP. Selected portions of Newfoundland can be considered to be highly sensitive precipitation receptors and thus even under a somewhat lower atmospheric deposition scenario exhibit reduced lake pH values. However, these west and south coast sites exhibit less drastic pH reductions than observed in many of the Nova Scotia sites. The Labrador and New Brunswick basins all have high median pH values indicating that the innate buffering capacity in these two regions is adequate to overcome the combined effects of atmospheric deposition and natural organic acidity.

8.3.6 Extractable aluminium

The acidification of aquatic systems is often accompanied by elevated heavy metal concentrations (Beamish 1976, Cronan and Schofield, 1979), many of which are toxic to aquatic biota. Much attention has been focussed on aluminium which is mobilized from the terrestrial basin and in ionic form can be extremely toxic (Driscoll et. al., 1980). However, as aluminium complexes with organic ligands, the use of total or extractable aluminium data in highly coloured waters may overestimate the potential metal toxicity. In an aluminium speciation study by Clair and Komadina (1984) using coloured waters from Kejimkujik National Park, it was found that approximately 95% of the aluminium is in complexed form and thus biological effects are minimized.

The extractable aluminium concentration histograms for Nova Scotia, Labrador and Newfoundland are presented in Figure 64. Labrador, Newfoundland and Nova Scotia have similar distributions with the concentrations centering around 0.10 mg/L and generally being less than 0.2 mg/L. The New Brunswick data are rather limited but do suggest that the aluminium concentrations are slightly lower than those observed for the other provinces.

The extractable aluminium concentration boxplots for the Nova Scotia basins are presented in Figure 65 and indicate rather high interbasin and intrabasin variability. In general the spatial pattern of aluminium mimics that of water colour with the exception of the basins around Halifax. Figure 66 indicates that many of the Nova Scotia basins have good relationships between extractable aluminium and dissolved organic carbon concentration. This suggests that basins such as 01ED which have high extractable aluminium concentrations probably have a relatively small percentage of the aluminium in labile form. Basins 01DE, 01DG and 01EJ have median aluminium concentrations which are among the highest recorded for basins in this province despite their low to moderate water colours. Kerekes et. al. (1984) have documented elevated aluminium concentrations in a clearwater lake near Halifax due presumably to increased mobilization of aluminium by pyrite weathering. This suggests that much of this aluminium is in labile form and thus the potential biological toxicity is high. The Nova Scotia basins which have low water colours and are not influenced by acid mine drainage have the lowest extractable aluminium with median values of approximately .05 mg/L. This suggests that labile aluminium values in the Nova Scotia basins are probably much lower than the .10 mg/L level at which Cronan and Schofield (1979) observed sublethal effects in brook trout.

The Newfoundland lakes have extractable aluminium boxplots (Figure 67) which are similar to those observed for the Nova Scotia basins both in magnitude and variability. The highest median extractable aluminium concentrations are generally observed in the highly coloured basins however the dissolved organic carbon and aluminium relationships are more poorly defined than in Nova Scotia. Several low water colour basins (02YC, 02YE, 02YO) have median extractable aluminium concentrations above 0.100 mg/L suggesting that some sites in these basins have a high potential for toxic aluminium effects.

Extractable aluminium concentrations in Labrador (Figures 68) are generally lower and less variable than those observed in insular Newfoundland or Nova Scotia. In all cases median values were below .100 mg/L and tended to parallel the water colour distributions. In those basins which have low water colours, the median extractable aluminium concentrations were approximately .05 mg/L, indicating that the labile aluminium concentrations are well below .100 mg/L. Although there is extremely limited extractable aluminium data available for New Brunswick, the boxplots for two southwestern basins (01AR, 01AQ) indicate that concentrations are well below .100 mg/L with basin medians being less than .05 mg/L (Figure 69). Thus as was apparent for Nova Scotia and Labrador, labile aluminium concentrations are in general expected to be low enough to minimize potential toxicity. However it must be cautioned that specific basins which have exposed mineralized slates or significant geological sources may experience elevated labile aluminium concentrations.

8.3.7 Ionic Ratios

The geochemical processes governing the aquatic chemistry response to atmospheric deposition are extremely complex and thus several authors (Bobee et. al., 1982; Jeffries, 1986) have employed various ion ratios as indicators of acidification. As acidification of aquatic systems is dependent on the interaction of deposition rate, natural acid loads and the system buffering capacity, the ratios used generally employ terms which indicate the acid load or potential acidification and the innate system alkalinity. One of the more useful ion ratios is the total alkalinity to excess calcium and magnesium ratio which can be used to give an indication of the relative extent of alkalinity lost to acidification. A major shortcoming of this and many other ratios is that they are unable to distinguish between the acidification effects of natural organic and anthropogenic mineral acid loads. In an attempt to overcome this problem Jeffries (1986) suggested the use of a ratio ($Alk-SO_4+A/Ca+Mg$) which was intended to correct for natural organic acid effects. However, due to the absence of DOC data, the effectiveness of this ratio was not tested. Using the Nova Scotia data, the Jeffries ratio was calculated but was found to be of limited utility as it failed to remove the effects of either organic or mineral acid loading. In fact this ratio provided only slightly more information than the alkalinity to excess calcium and magnesium ratio. Extending the concept of trying to correct for organic acidity a ratio was calculated (Alk+OA/Ca+Mg) which attempted to augment the present alkalinity with the alkalinity loss due to organic anions. The Nova Scotia boxplot of this ratio is presented in Figure 70 and indicates that most of the calculated ratios are above the theoretical upper limit of 1.0. Howell (1986) and Thompson (1986) have suggested that the Oliver (1983) organic anion empirical relationship gives an overestimate of the potential organic anion which suggests that the OA term in the ratio may be overestimating the alkalinity lost by organic acidity. Howell (1986) has shown that the calculated organic anion minus the sum of aluminium (3^+) and iron (3^+) agree with the difference between MTB and IC sulphate concentrations and has suggested that these two values give a better estimate of organic anion concentrations. Figure 71 presents the Nova Scotia basin boxplots of the ratio using organic anion concentrations minus aluminium and iron concentrations (ie Alk+{OA-(Al+Fe)}/Ca+Mg). Due to limited data, this ratio will only be calculated for the Nova Scotia basins. Although this ratio appears more realistic, there are still some difficulties in some basins (01EC, 01EN) which have many values above the theoretical upper limit. However, it must be remembered that this ratio is calculated from eight water quality parameters (alkalinity, calcium, magnesium, pH, DOC, aluminium, iron and chloride) and thus the probability of compounded analytical errors is high. In addition, organic waters may have important contributions from other buffering systems which are not adequately represented in this ratio. Despite these problems, this ratio does appear to have some utility in predicting the relative amount of alkalinity loss that can be attributed to mineral acid loading. By far the lowest ratios observed are for the basins near Halifax which are influenced by pyrite weathering and/or local sulphur emissions. These basins (01DE, 01DG, 01EJ, 01EK) have all lost more than half of their original bicarbonate alkalinity. The southwestern Nova Scotia basins exhibit less alkalinity loss due to mineral acid loads, varying from a high of 30% for basin 01DA to a low of 15% for basin 01ED. This emphasizes that although the present atmospheric deposition rate in southwestern Nova Scotia is not sufficient to result in a complete alkalinity loss, mineral acidity can be a significant contributor to the overall acid load. Basin 01FD in northern Cape Breton is interesting in that despite the low expected atmospheric deposition, mineral acidity can account for approximately 40% of the experienced alkalinity loss. It should be emphasized that due to the uncertainty associated with the organic anion term of the ratio, the percentage losses may be inconsistent with observations made using individual parameters or models. However the ratio does suggest that basins 01FD and 01DA have the most pronounced effects due to LRTAP.

8.3.8 Models

Numerous geochemically based acidification models have been developed and range from simple regression based models (Henriksen 1980; Thompson, 1982) up to complex computer simulations (Lam et al., 1985). Although many of these models address the overall acidification of a system, others are much more specific, dealing with short term processes such as snowmelts. The data set used in this report is comprised of median concentrations of lakes and rivers with vastly different sampling regimes and thus the discussion will be restricted to the regression models given by Henriksen (1979, 1980). Although it is realized that models dealing with ionic flux such as that given by Thompson (1982) may be more meaningful, the lack of discharge data for individual stations precludes their consideration.

Based on the assumptions that the sum of excess calcium and magnesium should be approximately equal to total alkalinity in pristine waters and that the excess calcium to excess magnesium ratio should be essentially constant, Henriksen (1979) suggested that plots of pH and calcium could be used to distinguish between acidified and unacidified systems. Thus by comparing the Atlantic region data to the theoretical "acidification indicator" line it is possible to estimate the percentage of sites which have shown some acidification. Henriksen (1980) also developed a nomograph based on the principle that acidification of freshwaters is analogous to a large scale bicarbonate titration with strong mineral acid. This nomograph uses excess calcium and magnesium as an indicator of pre-acidification alkalinity and excess sulphate to indicate the degree of acidification. Henriksen cautions that the validity of the nomograph depends on the assumptions that the cation weathering rate remains constant regardless of the rate of acidification and that the acidification is due to strong mineral acids. Church and Galloway (1984) have further reviewed these two models and have pointed out some additional difficulties, with particular reference to relationships with precipitation pH. One difficulty with use of these models for systems in Atlantic Canada is that they are not designed to account for acidification by weak organic acids. However several authors (Scruton, 1983; Kerekes et. al., 1984; Howell, 1986) have shown that the nomogram can predict the pH of coloured lakes providing sulphate (MTB) concentrations are used. Similarly, Howell (1986) has indicated that the nomogram gives a reasonably accurate precipitation pH estimate when sulphate (IC) concentrations are employed. Thus it appears that the sulphate (MTB) based nomogram can be used to indicate the combined effects of mineral and organic acidity while the sulphate (IC) based nomogram indicates the acidification due to strong mineral acid loading.

The previous sections have indicated that several of the hydrometric basins have geological sources of sulphate which may confuse the interpretation of the model outputs. For this reason, the following discussion almost exclusively focuses on those basins in which lake sulphate concentrations are considered to reflect atmospheric deposition.

Basins 01EA is located in southwestern Nova Scotia in the area of highest expected atmospheric deposition. The Henriksen "acidification indicator" (Figure 72a) shows that roughly 60% of the lakes in this basin fall above the theoretical line indicating that these sites have been acidified. The sulphate (IC) nomogram supports this with several of the lakes lying within the transition zone (Figure 72c), suggesting that strong mineral acidity in this basin has been sufficient to cause some acidification. In addition, the sulphate concentrations of lakes in this basin would predict a precipitation pH of approximately 4.55 which agrees well with the average precipitation pH range of 4.45 to 4.57 (1977-1980) given by Underwood et. al. (1986) for three stations in southwestern Nova Scotia. This coupled with the low sulphate concentration variability and the good agreement between excess lake sulphate and precipitation sulphate further supports the contention that strong mineral acidification in this part of the province is due to LRTAP, not pyrite weathering. Figure 72b presents the sulphate (MTB) based nomogram for a subset of the lakes in basin 01EA. The increased variability along the abscissa indicates that natural organic acids are also implicated in the acidification of some of the lakes in this basin. In the highly coloured basins, the combined effects of natural and anthropogenic acid loads have resulted in significant acidification. Although the figures are not presented, very similar observations can be made for the other extreme southwestern (01DA) and Fundy coast basins (01DB, DC, DD).

Basin 01ED in southwest Nova Scotia includes some of the most geologically sensitive systems in Nova Scotia as indicated by the extremely low excess calcium concentrations in Figure 73a. As was observed for basin 01EA approximately 60% of lakes lie above the Henriksen line indicating that some acidification has occured. The sulphate (IC) nomogram (Figure 73b) agrees with this, having a large percentage of the values lying in the transition and acid lake zone. Thus despite the lower expected atmospheric deposition, the high terrain sensitivity has resulted in acidification of lakes in these basins due to mineral acid loading. Using an average excess sulphate (IC) concentration of approximately .03 meq/L, the nomogram predicts a precipitation pH of 4.68 which agrees well with the 4.7 value for the 1984 CAPMoN data for Kejimkujik National Park (Vet et. al., 1984). The sulphate (MTB) nomogram exhibits the extreme effects of organic acidity skewing the data to the right along the abscissa (Figure 73c). This diagram indicates that organic acidity has significantly contributed to the overall acidity, with most of the lakes lying in the transition or acid lake region of the nomogram. Thus the potential acidification of lakes in basins 01EC and 01ED is high due to the combined effects of extreme terrain sensitivity, moderate atmospheric loading and natural organic acidity.

The Henriksen excess calcium versus pH plot for the basins 01FC and 01FD in northeastern Cape Breton is presented in Figure

74a. This figure is similar to that observed for basin 01ED in that the excess calcium concentrations are extremely low and about 50% of the sites exhibit some indication of acidification. The sulphate (IC) nomogram (Figure 74b) indicates that even though the deposition rate is expected to be the lowest in the province, the extremely high lake basin sensitivity has resulted in several sites lying within the transition zone and one site in the acid lake range. Given the average excess sulphate concentration of approximately .015 meq/L, the nomogram predicted pH is 4.8 which agrees well with the 4.9 value given by Underwood et. al. (1986). Figure 74c presents the sulphate (MTB) nomogram and as was seen for the 01EC and 01ED basins there is increased variability along the abscissa. This figure indicates that organic acids also contribute significantly to the acidification of Cape Breton lakes with more than half of the sites falling in the transition or acid lake zones.

For the sake of comparison the Henriksen plots for lakes in the 01EJ basin near Halifax are presented in Figures 75a to 75c. These basins not only receive LRTAP sulphates but also have varying contributions from point source emissions and pyrite weathering. Figure 75a indicates that nearly all of the lakes in this basin have undergone some degree of acidification despite relatively high innate buffering potential. The sulphate (IC) nomogram (Figure 75b) is interesting in that there is a large amount of variability on the abscissa. This variability emphasizes that the lakes in this basin are under the control of varying contributions of LRTAP, point source and pyritic origin sulphates. It is also of interest to note that several of the high excess calcium and magnesium lakes are near to the transition zone indicating the extreme acidification commonly associated with acid mine drainage. A similar pattern is observed for lakes located in basins 01DE and 01DG to the north of Halifax.

The New Brunswick lake data are extremely limited, with the majority of the sites being situated in the southwestern basins (01AR & 01AQ) of the province. Figure 76a indicates that approximately 60% of the New Brunswick lakes have been acidified which is consistent with the high expected atmospheric deposition. The sulphate (IC) nomogram (Figure 76b) indicates that there is considerable variability in excess sulphate concentrations probably due to geological sources such as gypsum. The nomogram basically agrees with the excess calcium versus pH plot, except that most of the lakes are in the bicarbonate zone while a few sites are in the transition lake region. The sulphate (MTB) nomogram (Figure 76c) is essentially identical to the sulphate (IC) based figure which indicates that natural organic acidity is of minor importance in the overall acidification process. The fact that most of the New Brunswick lakes lie in the bicarbonate zone indicate that the innate buffering capacity is sufficient to overcome the present loading regime.

The lakes on the Great Northern Peninsula of Newfoundland are underlain by rather diverse geological structures and thus the excess calcium concentrations are highly variable. The Henriksen excess calcium versus pH plot (Figure 77a) indicates that approximately 30% of the sites have experienced some acidification. The sulphate (MTB) based nomogram (Figure 77c) confirms the "acidification indicator" plot with about 50% of the sites falling in the transition or acid lake region. There is some scatter along the abscissa indicating variable organic anion influence. The sulphate (IC) nomogram (Figure 77b) has limited data but shows much less scatter along the sulphate axis. The fact that the points on this figure all fall in the bicarbonate or borderline transition lake zone suggests that the present atmospheric deposition in this region is not sufficient to result in large scale acidification. However when this LRTAP sulphate of approximately .02 meq/L is coupled with natural organic acidity, those systems with high terrain sensitivity can be expected to lose their bicarbonate alkalinity. The predicted precipitation pH from the nomogram is about 4.7 which compares with the median value found in precipitation at Cormack. The results for basins 02YH, 02YL and 02YK on the west coast closely parallel the findings of the Great Northern Peninsula basins. The basins located on the south coast of Newfoundland have both high terrain sensitivity (basins ZB to ZE) and relatively low sulphate depositions. The Henriksen "acidification indicator" plot indicates that only a small percentage of the south coast lakes have been acidified (Figure 78a). The sulphate (MTB) nomogram (Figure 78c) confirms this with only two of the lakes found in the transition lake region. The scatter along the sulphate axis indicates that organic acidity is involved and many of the sites are very near to the 5.3 pH line. The sulphate (IC) data (Figure 78b) all fall in the bicarbonate region and thus as was noted for the Great Northern Peninsula, the present mineral acid load is not by itself sufficient to result in complete loss of the bicarbonate alkalinity. The precipitation pH predicted from the nomogram is approximately 4.75 which is slightly lower than the Bay D'Espoir median CAPMoN value of 4.96.

The southern Labrador basins fall on or below the theoretical Henriksen line (Figure 79a) and thus have not experienced significant acidification. The sulphate (MTB) nomogram (Figure 79b) supports this with all lakes lying in the bicarbonate lake zone of the graph. Thus in this region of Labrador the combined effects of mineral and organic loading are not sufficient to completely deplete the basin alkalinity. The central and northern basins (Figure 80a) have approximately 5% of the sites lying above the "acidification indicator" line. The Henriksen nomogram (Figure 80b) agrees rather well with a few sites lying in the transition region.

9. Long Term Trends

9.1 Statistical Approach

Numerous rivers in Atlantic Canada have been sampled under several water quality monitoring programs and have data dating back to 1965. Twenty-eight of these rivers comprise the WQB LRTAP river monitoring program and are presently sampled on a monthly basis. These rivers are located in all four of the Atlantic provinces with particular emphasis on Nova Scotia and insular Newfoundland. Because of the relatively long periods of record for these rivers, it was felt that a retrospective analysis of temporal patterns of LRTAP related chemical constituents would be beneficial.

Prior to discussing the statistical treatments used and the results, it must be pointed out that the data employed were not originally collected specifically to address LRTAP related questions or to investigate long term trends. For this reason, the data set has some major deficiencies including irregular sampling intervals, large gaps in the record and changing analytical techniques with little or no overlap of analytical methods. Although these shortcomings preclude the use of many time series techniques such as Box-Jenkins models, these data sets are among the best available for investigation of the temporal trends.

The purpose of the statistical analysis performed by Green et al. (1986) was to identify changes or trends over time in water quality parameters which are related to the acidification of surface waters in Atlantic Canada. The main approach was to use the statistical analysis as an exploratory tool rather than for model-fitting, as it was desirable to identify patterns rather than to test whether or not they confirmed preconceived notions of what the patterns could be. Patterns observed graphically were tested with a posteriori models to see if there was evidence that the patterns could be explained by temporal variability. The graphical techniques employed included scatterplots, median plots, and running boxplots. The statistical techniques included linear models and before and after median comparisons. The linear models used were essentially two-way ANOVA's of medians which were weighted according to the number of observations used in the calculations. The two ANOVA factors were year and river which enabled an estimation of year effects after river effects had been accounted for. The analysis was carried out on Nova Scotian and Newfoundland rivers using complete annual data sets as well as seasonal subsets. Preliminary analysis and residual examination indicated more satisfactory model fits could be achieved after square root transformation of alkalinity, sulphate and dissolved organic carbon. The pH data had a reasonable residual behaviour without transformation. A more detailed description of the graphical and statistical techniques and the results obtained is presented in the report by Green et al. (1986). The following sections present a synthesis of these results in addition to some discussion of temporal changes in river ion exports in relation to changes in emission and deposition rates.

9.2 pH

Of all the data considered in the statistical analyses, the pH data set was the most complete and the least affected by changing analytical methodology. Although the meters and electrodes have undoubtedly changed, all the pH data employed are laboratory potentiometric measurements (NAQUADAT Code 10301L).

The running boxplots of pH for selected Nova Scotia and Newfoundland rivers are presented in Figure 81 and indicate that low median pH values were frequently observed during the late 1960's and early 1970's. After 1973 these pH levels tend to increase to levels equal to or above the values observed at the beginning of the data record. The ANOVA tables for the Nova Scotia and Newfoundland river pH data are presented in Table 18. These results indicate that the periods of low pH observed from 1967 to 1973 are statistically significant. These findings confirm those given by Thompson (1986) who observed lower median pH values and higher sulphate yields during 1971-1973 than in 1982-1984 for Atlantic Canada rivers.

In some cases, statistical analysis of annual water quality data may obscure long term patterns which have a seasonal component and thus the ANOVA was also run on three seasonal data sets (spring, summer, winter). The Newfoundland rivers appeared to have a strong seasonal component, having significantly lower spring pH values from 1967 to 1973. Although several of the running boxplots indicated pH depressions during 1982-1983, the ANOVA indicates that these low values were not statistically significant.

Plots of the fitted yearly pH values from the ANOVA model for the Nova Scotia and the Newfoundland rivers are given in Figure 82. It should be noted that the pH values on these figures represent the provincial composite values and that although individual rivers are expected to follow the same temporal pattern the actual pH levels may be shifted up or down. The pH of the Nova Scotia rivers declined slowly from 1966 and reached a minimum in 1973. After 1973, the pH values began increasing and experienced a period of highly variable values between 1975 and 1980. Following this, the median pH values appeared to stabilize at levels similar to those observed during the early part of the record. The Newfoundland river pH temporal pattern appears to be somewhat more dramatic than that observed for the Nova Scotia rivers. However, the statistical analysis considered pH values rather than the hydrogen ion concentration which, given the higher Newfoundland river pH levels, probably accounts for the apparently greater pH depressions. The pH of the Newfoundland rivers declined steadily from 1966 and reached a minimum in 1973. This represents a pH decline of approximately 0.5 pH units over the six year time span. By 1975, the pH values had recovered to levels similar to those observed during the start of the period of record and remained relatively stable from 1975 to 1984. These results indicate that rivers in both Nova Scotia and Newfoundland have experienced reduced pH levels due to acidification. The lowest pH levels correspond to a period of high sulphate export (Thompson, 1986) and recent increases in pH (1975-1984) agree with the recent decreases in sulphur emissions (Figure 83).

A major concern with these statistical results is that by ignoring discharge, some of the observed patterns may reflect changes in hydrology not atmospheric deposition. For this reason it is beneficial to consider changes in hydrogen ion export as well as pH. However due to the low sampling frequency, annual estimates of ionic export can be expected to be highly variable. A common method of calculating ionic exports is to take the product of the discharge weighted annual mean concentration and the annual discharge (Thompson, 1986). However given the small sample size and the inherent variability (both analytical and real) in much of the water quality data, the mean value may be a poor estimator of central tendency due to the influence of extreme values. Another factor which may influence the ion export estimate is whether daily or monthly mean discharge values are used in the calculations. This is a particularly important consideration when calculating ion exports for the south coast of Newfoundland rivers which respond very rapidly to precipitation events. Figures 84a to 85b present hydrogen ion export estimates for selected rivers in Nova Scotia and Newfoundland using several alternate methods of calculation. Regardless of the method used for calculaton, these figures exhibit similar temporal patterns. In all cases the mean and/or median hydrogen ion exports were highest during the early part of the data record and generally peaked during 1972 and 1973. From 1975 to

1984 the hydrogen exports decreased except for slightly elevated values observed during 1982 and 1985. In addition the interquartile range of export estimates were significantly higher during the early portion of the record. Although some of this is undoubtedly the result of improved analytical quality control, this may also indicate a higher frequency of high hydrogen export events during 1969 to 1974. Similarly, higher interquartile ranges observed during 1982-1983 may also be indicative of higher hydrogen export events. These results agree well with the pH ANOVA results and indicate that the significantly lower pH values observed in Nova Scotian and Newfoundland rivers during the early 1970's were not the result of changes in the hydrologic regime. In addition as the slightly lower median pH values observed for many of the rivers during 1982 are also reflected in the hydrogen export calculations, it is unlikely that these depressions are due entirely to changes in the discharge pattern.

Figure 83 presents the annual patterns of sulphur emissions in the USA and Eastern Canada. This figure indicates that the periods of highest emissions and deposition generally coincide with the lowest pH values and highest hydrogen ion exports for rivers in Nova Scotia and Newfoundland. This rather strong linkage between sulphur emissions and water chemistry indicates that these highly sensitive receptor systems in Atlantic Canada have not only experienced acidification due to anthropogenic mineral acid loading but that they also can be employed as effective monitors of the aquatic response of future emission control strategies.

9.3 Sulphate

Given the patterns observed for river pH values and hydrogen ion exports in Newfoundland and Nova Scotia, it would be expected that changes in sulphate concentrations and exports would behave similarly. However sulphate is a much more difficult parameter to analyse due to several analytical problems encountered during the period of record. Sulphate has been analysed by three different methods which are not comparable. From 1966 to 1972, sulphate was measured using a Thorin indicator technique (16303L) which is applicable for measurement of surface waters with concentration ranges of 5 to 150 mg SO_4/L. The accuracy of this method in the 5 - 150 mg/L range is given as 1.5 mg/L with a precision of 0.7 mg/L (ASTM, 1969). Given that concentrations of sulphates in Nova Scotian and Newfoundland rivers are characteristically below 5.0 mg/L, the accuracy and precision of the early sulphate measurements must be questioned and thus the data must be used cautiously. Figure 86 presents the sulphate concentrations of two rivers over time and indicates much greater sulphate variability during the early part of the data record. Commencing in 1972, sulphate concentrations were measured colourimetrically, using a methyl thymol blue indicator. Several authors (Kerekes et. al., 1984; Cheam et al., 1985; Howell and Pollock, 1986) have indicated that this method is inappropriate for measurement of sulphate concentrations in coloured waters due to organic anion interference. The sulphate concentration plot for two low water colour rivers (Figure 86a,b) also indicates that the sulphate (MTB) variability was much greater during 1973-1977 than from 1980-1985. This can be explained to some extent by an improvement in accuracy associated with a reduction in the analytical range from 1-100 mg/L to 1-20 mg/L during 1976. Thus, as was the case for the Thorin sulphate, the early sulphate (MTB) must also be used with caution. In 1981, sulphate concentrations were also measured by ion chromatography, a method which Cheam et al. (1985) feel gives the most reliable measure of sulphate concentration in both clear and coloured waters.

The statistical analysis of sulphate concentration changes over time has concentrated on Thorin (16309) and MTB (16304) sulphate. The sulphate (IC) data have been excluded as they span a relatively small time period. These analyses indicate that there has been no significant annual or seasonal patterns of river sulphate concentration over time. Similar results were observed by Clair and Whitfield (1983) who found variable patterns from selected Atlantic Canada Rivers using Box-Jenkins analysis. There has been a significant decrease in variability (interquartile range) in sulphate concentrations since 1977 which probably reflects some of the previously discussed analytical problems. Although the analytical variability cannot be ruled out, it is also possible that some of this variability may be due to high deposition events during the years when industrial emissions were at a maximum. However, it is not possible to separate the systematic and the analytical variability and thus actual temporal patterns in sulphate concentrations are obscurred.

Thompson (1985, 1986) has compared mean sulphate exports for selected Nova Scotia and Newfoundland rivers using discrete date ranges of the same long term data sets. Comparisons of the 1971-1973 mean Thorin sulphate exports with the 1981-1983 and 1982-1984 mean ion chromatograph sulphate exports have indicated significant reductions in sulphate exports during the 1980's. However given the differences in data variability over time, the extent of these changes in sulphate export may be dependent on the statistic used to indicate central tendency. As was done for H^+ ion export, sulphate exports for selected clearwater rivers were calculated using daily and monthly mean discharges and annual mean and median values. The mean excess sulphate exports for the Isle Aux Morts River in southwestern Newfoundland based on daily mean discharge (Figure 87a) and to a lesser extent monthly mean discharge (Figure 88a) suggest that exports have generally declined during the period of record. However, the boxplots presented in Figures 87b and 88b indicate that there has been no consistent decrease in median annual sulphate exports over time. Similar results were also apparent for the Wallace River in Nova Scotia (Figures 89 to 90). Thus unlike the hydrogen export calculations, the four calculation methods do not present a consistent pattern of sulphate export decrease during the 1980's. If one assumes that the high variability in sulphate concentrations and exports observed during the early part of the record reflects actual system variability, then the mean values probably give the best indication of annual sulphate export and would thus indicate that sulphate exports have decreased since the early 1970's. However, if much of the variability during the early part of the record is due to analytical error, then the median values probably give the best indication of annual sulphate exports. Using the median values, there has been no significant reduction in sulphate exports over the period of record. Thus it appears that although there may have been significant changes in recent sulphate exports, these changes have been obscured by noise in the early part of the data record. Because of this noise it is not possible to use the historical sulphate data to confirm or reject the patterns or trends observed for the river pH and hydrogen ion exports.

9.4 Additional Parameters

In addition to pH and sulphate, several other LRTAP related parameters were included in the statistical analysis. However, the patterns observed for many of these parameters appear to be merely artifacts of changing analytical methodology, patchy data sets and high percentages of censured data.

Total alkalinity concentrations for most of the rivers in Atlantic Canada are at or close to the detection limit and thus the statistical results are highly susceptable to changes in analytical methodology. Prior to 1980, total alkalinities were measured by a fixed endpoint titration, a method which is both imprecise and inaccurate near the detection limit. After 1980, samples with pH values below 6.0 had alkalinity concentrations determined by Gran Plot titrations. This method is not only more accurate and precise but also has greater sensitivity as there is no lower detection limit. The statistical analysis indicated that rivers in Nova Scotia and to a lesser extent Newfoundland had significantly lower total alkalinity concentrations during the 1980's. These results parallel the change in the analytical methodology and suggest that the apparent pattern is merely a function of a lowering of the detection limit. Thus, as was observed for sulphate, methodological problems associated with the measurement of total alkalinity may be obscuring the actual system response.

Dissolved organic carbon concentrations were also considered in the statistical treatment but as a consequence of the relatively short period of record many of the statistical techniques were not appropriate. Figure 91 indicates that many of the rivers have experienced reduction in dissolved organic carbon concentrations after 1980. This coincides with a change in analytical methodology and thus some of the DOC reduction may be attributed to differences in methodology. However, this figure also indicates that many of the rivers which have exhibited DOC reductions have also undergone concomitant reductions in extractable aluminium concentrations. As DOC and extractable aluminium concentrations are usually well correlated, this would suggest that some of the observed reduction in DOC concentration is real.

10. REFERENCES

ASTM, 1969. The 1969 Book of ASTM Standards with Related Material, Part 23. Water; Atmospheric Analysis American Society for Testing and Materials. Philadelphia, Pa.

Barrett, E. and G. Brodin, 1955. The Acidity of Scandinavian Precipitation. Tellus 7:251-257.

Beamish, R.J., 1976. Acidification of lakes in Canada by acid precipitation and the resulting effects on fishes. Water, Air and Soil Poll. 6:501-504.

Bobbee, B., Y. Grimard, M. LaChance and A. Tessier, 1982. Nature et etendue de l'acidification des lacs du Quebec. INRS - Eau, rapport scientifique No. 140, 234 p. 3 appendices.

Bobbee, B. and M. Lachance, 1984. Multivariate Analysis of Parameters Related to Lake Acidification in Quebec. Water Resources Bulletin 20(4):545-556.

Cheam, V., A.S.Y. Chau and S. Todd. 1985. Sulphate in Coloured Waters: Investigation on Methodologies, Data Reliability, and Approaches to Salvage Historical Colourimetric Data. NWRI Report. Contribution Number 85-95. National Water Research Institute.

Church, J.R. and J.N. Galloway, 1984. Application of Henriksen's Acidification Indicator and Predictor Nomograph to Two Adirondack Lakes. Water, Air and Soil Poll. 22:111-120.

Clair, T.A., J.P. Witteman and S. Whitlow. 1981. Acid precipitation sensitivity of Canada's Atlantic provinces. Environment Canada, Inland Waters Directorate, Water Quality Branch, Technical Bulletin No. 124, 12 p.

Clair, T.A. and P.H. Whitfield. 1983. Trends in pH, calcium and sulphate of rivers in Atlantic Canada. Limnol. and Oceanogr., 28(1):160-165.

Clair, T.A. and V. Komadina. 1984. aluminium Speciation in Waters of Nova Scotia and Their Impact of WQB Analytical and Field Methods. Inland Waters Directorate, Water Quality Branch. Report No. IWD-AR-WQB-84-69. October 1984.

Cronon, C.S. and C.L. Schofield. 1979. aluminium Leaching Response to Acid Precipitation: Effects on High Elevation Watersheds in the Northeast. Science 204:304-306.

Driscoll, C., J. Baker, J. Bisagni, and C. Schofield. 1980. Effects of aluminium Speciation on Fish in Dilute, Acidified Waters Nature 284:161-164.

Dovland, H., E. Joranger and A. Semb, 1976. Deposition of Air Pollutants in Norway. in F.H. Braekke (ed), Impact of Acid Precipitation on Forest and Freshwater Ecosystems in Norway. SNSF-Project FR 6/76. Pp 15-35.

Freedman, B., C. Stewart and U. Prager. 1985. Patterns of Water Chemistry of Four Drainage Basins in Central Nova Scotia. Inland Waters Directorate, Water Quality Branch. Report No. IWD-AR-WQB-85-93.

Gjessing, E.T., A. Henriksen, M. Johannessen and R.F. Wright, 1976. Effects of Acid Precipitation on Freshwater Chemistry. in F.H. Braekke (ed), Impact of Acid Precipitation on Forest and Freshwater Ecosystems in Norway. SNSF - Project FR 6/76. Pp 65-85.

Gorham, E., J.K. Underwood, F.B. Martin and J.G. Ogden. 1986. Natural and Anthropogenic Causes of Lake Acidification in Halifax County, Nova Scotia. Nature (in press).

Grahn, D., H. Hultberg and L. Landner, 1974. Oligotrophication - a self-accelerating process in Lakes Subjected to Excessive Supply of Acid Substances. Ambio 3:93-94.

Green, P.E.J., B. Freedman, C.A. Field, D. Hamilton and C. Stewart. 1986. Analysis of Water Chemistry Data for 28 Rivers in

Atlantic Canada. Inland Waters Directorate. Water Quality Branch. Report No. IWD-AR-WQB-86-115. December, 1986.

Hem, J.D. 1970. Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey Water Supply Paper 1473, 363 p.

Henriksen, A. 1979. A Simple Approach for Identifying and Measuring Acidification of Freshwater Nature 278:542-545.

Henriksen, A. 1980. Acidification of Freshwaters - A Large Scale Titration. p. 68-74. In D. Drablos and A. Tollan (ed.) Ecological Impact of Acid Precipitation.

Howell, G.D. 1986. Water Quality Characterization of 78 Acid Precipitation Monitoring Lakes in Atlantic Canada. Inland Waters Directorate, Water Quality Branch. Report No. IWD-AR-WQB-86-109. July, 1986.

Howell, G.D. and T.L. Pollock. 1986. Sulphate, Water Colour and Dissolved Organic Carbon Relationships in Organic Waters of Atlantic Canada. In Proceedings of the Workshop on the Statistical Aspects of Water Quality Monitoring. Burlington. October, 1985. In press.

Jeffries, D.S. 1986. Evaluation of the Regional Acidification of Lakes in Eastern Canada using Ion Ratios. NWRI Report. Contribution Number 86-79. National Water Research Institute. Canadian Centre for Inland Waters, Burlington, Ontario.

Jones, M.L., D.R. Narmorek, B.S. Reuber, P.J. McNamee and L.P. Rattie, 1986. Brown Waters: Relative Importance of External and Internal Sources of Acidification on Catchment Biota. Review of Existing Knowledge. ESSA Environmental and Social Systems Analysis Ltd., March, 1986.

Kelso, J.R.M., C.K. Minns, J.E. Gray and M.L. Jones. 1986. Acidification of Surface Waters in Eastern Canada and its Relationship to Aquatic Biota. Can. Spec. Publ. Fish. Aquat. Sci. 87. 42 p.

Kerekes, J.J., G. Howell, S. Beauchamp and T. Pollock. 1982. Characterization of Three Lake Basins Sensitive to Acid Precipitation in Central Nova Scotia (June, 1979, to May, 1980). Int. Revue ges Hydrobiol. 67(5):679-694.

Kerekes, J.J., G. Howell and T. Pollock. 1984. Problems Associated with Sulphate Determinations in Coloured, Humic Waters in Kejimkujik National Park, Nova Scotia (Canada). Verh. Internat. Verein. Limnol. 22:1811-1817.

Kerekes, J.J., B. Freedman, G. Howell and P. Clifford. 1984. Comparison of the Characteristics of an Acidic Eutrophic, and an acidic oligotrophic lake near Halifax, Nova Scotia. Water Pollution Research Journal of Canada. 19:1-10.

Kerekes, J.J. and T.L. Pollock. 1983. Comment on the Interpretation of Sulphate Ions in Watt et al. 1983. Evidence of the Acidification of Some Nova Scotia Rivers and its Impact on Atlantic Salmon, _Salmo_ _Salar._ _Can._ _J._ _Fish._ _Aquat._ _Sci._ 40:462-473.

Kerekes, J., S. Beauchamp, R. Tordon and T. Pollock. 1986. Sources of Sulphate and Acidity in Wetlands and Lakes in Nova Scotia. Water, Air and Soil Poll. (in press).

Kramer, J.R., A.W. Andren, R.A. Smith, A.H. Johnson, R.B. Alexander and G. Oehlert. 1985. Streams and Lakes. Chapter 7. Acidic Deposition: Long Term Trends. National Academy of Sciences.

Lam, D.C.L., S. Boregowda, A.G. Bobba, D.S. Jeffries and G.G. Patry. 1985. Interfacing Hydrological and Hydrogeochemical Models for Simulating Acidification Effects in Canadian Watersheds. In Proc. Int. Symp. on Acidic Deposition, Muskoka Conference, Ontario, 1985.

In press.

Machell, J.R., J.F. Wiltshire and R. Donald. 1983. The Effect of Halifax Air Emissions on the Water Quality of Thirty-Six Halifax Area Lakes, 1980. Environmental Protection Service. Surveillance Report EPS-5-AR-84-2. February, 1983.

Machell, J.R., J.F. Wiltshire, D. Walter and R. Donald. 1985. A Study of Acidification in Seven Lakes in Mainland, Nova Scotia, 1979-1981. Environmental Protection Service. Surveillance Report EPS-5-AR-85-1. February, 1985.

Martin, H.C. and T.G. Brydges. 1986. Stress Factors: Trends and Recovery. The International Conference on Acidification and its Policy Implications. Amsterdam. May, 1986.

McNeely, R.N., V.P. Neimanis and L. Dwyer, 1979. Water Quality Sourcebook. Inland Waters Directorate, Ottawa, Canada.

MOI, 1983. United States - Canada Memorandum of Intent. Impact Assessment, Work Group 1, Final Report, January, 1983.

NRC, 1981. Acidification in the Canadian Aquatic Environment. Prepared by the Associate Committee on Scientific Criteria for Environmental Quality. National Research Council of Canada. NRCC #18475.

Oliver, B.G., M. Thurman and R.L. Malcolm. 1983. The Contribution of Humic Substances to the Acidity of Coloured Natural Waters. Geochim. Cosmochim. Acta., 47:2031-2035.

Pearce, P.H., F. Bertrand and J.W. Macharen. 1985. Currents of Change. Inquiry on Federal Water Policy. Final Report. September, 1985.

Scruton, D.A. 1983. A Survey of Headwater Lakes in Insular Newfoundland, with Special Reference to Acid Precipitation. Can. Tech. Rep. Fish. Aquat. Sci. 1195:v + 110 p.

Scruton, D.A. 1984. A Survey of Selected Lake in Labrador, with an Assessment of Lake Status and Sensitivity in Relation to Acid Precipitation. Can. Tech. Rep. Fish. Aquat. Sci. 1296:v + 115 p.

Shaw, R.W. 1979. Deposition of SOx and NOx in Atlantic Canada. Environmental Science and Technology 13(4):406-411.

Shaw, R.W. 1982. Deposition of Atmospheric Acid from Local and Distant Sources at a Rural Site in Nova Scotia. Atmospheric Environment 16(2):337-348.

Thompson, M.E. and M.B. Hutton. 1985. Sulphate in Lakes of

Eastern Canada: Calculated Yields Compared with Measured Wetland Dry Deposition. Water, Air and Soil Poll. 24:77-83.

Thompson, M.E. 1982. The Cation Denudation Rate as a Quantitative Index of Sensitivity of Eastern Canadian Rivers to Acidic Atmospheric Precipitation. Water, Air and Soil Poll. 18:215-226.

Thompson, M.E. 1985. Cation Denudation Rates of Rivers in Nova Scotia, 1971-1974 and 1977-1982. NWRI Report. Contribution Number 85-28. National Water Research Institute.

Thompson, M.E. 1986. Chemical Trends in Coastal Rivers of Eastern Canada. NWRI Report. Contribution Number 86-1. National Water Research Institute.

Thompson, M.E. 1986. The Effects of Organic Anions on Alkalinity Measurements in Organic-Rich Waters in Nova Scotia. NWRI Report. Contribution Number 86-9. National Water Research Institute.

Underwood, J.K., J.G. Ogden, J.J. Kerekes and H.H. Vaughn. 1986. Acidification of Nova Scotia Lakes III. Atmospheric Deposition of SO_4 and NO_3 and Effects on Urban and Rural Lakes - Water, Air and Soil Poll. 29 (in press).

Underwood, J.K. and P.Y. Schwartz. 1986. Acidic Lakes in Nova Scotia: Estimates of Numbers and Areas. Nova Scotia Department of the Environment. Manuscript Report. 14 p.

Vet, R.J., W.B. Sukloff, M.E. Mill and R. Gilbert. 1986. Capmon Precipitation Chemistry Data Summary 1983-84. Atmospheric Environment Service. Environment Canada. Report No. AQRB-86-001-M March, 1986.

Watt, W.D., D. Scott and S. Ray. 1979. Acidification and Other Chemical Changes in Halifax County Lakes after 21 years. Limnol. Oceanogr. 24:1154-1161.

Watt, W.D., C.D. Scott and W.J. White. 1983. Evidence of Acidification of some Nova Scotian Rivers and its impact on Atlantic Salmon, Salmo Salar. Can. J. Fish. Aquat. Sci. 40:462-473.

Wiltshire, J.F. and J.R. Machell. 1981. A Study of Acidification in Sixteen Lakes in Mainland Nova Scotia and Southern New Brunswick. A Preliminary Report. Environmental Protection Service. Surveillance Report EPS-5-AR-81-4.

Wright, R.F. 1983. Predicting Acidification of North American Lakes. Norwegian Institute for Water Research (NIVA)

Report 4/1983. Oslo, Norway. 165 pp.

WQB. 1979. Analytical Methods Manual. Inland Waters Directorate, Environment Canada, Ottawa, Ontario.

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12. LIST OF PLATES

Plate 1 A Regional Overview of Excess Calcium and Magnesium Concentrations in Atlantic Canada.

Plate 2 A Regional Overview of Water Colour in Atlantic Canada.

Plate 3 A Regional Overview of Excess Sulphate (IC) Concentrations in Atlantic Canada.

Plate 4 A Regional Overview of Total Alkalinity Concentrations in Atlantic Canada.

Plate 5 A Regional Overview of the Ratio of Total Alkalinity to Excess Calcium and Magnesium in Atlantic Canada.

Plate 6 A Regional Overview of pH Values in the Atlantic Provinces.

PLATE 1

A Regional Overview of Excess Calcium and Magnesium Concentrations in Atlantic Canada, based on Hydrometric Basin Median Values

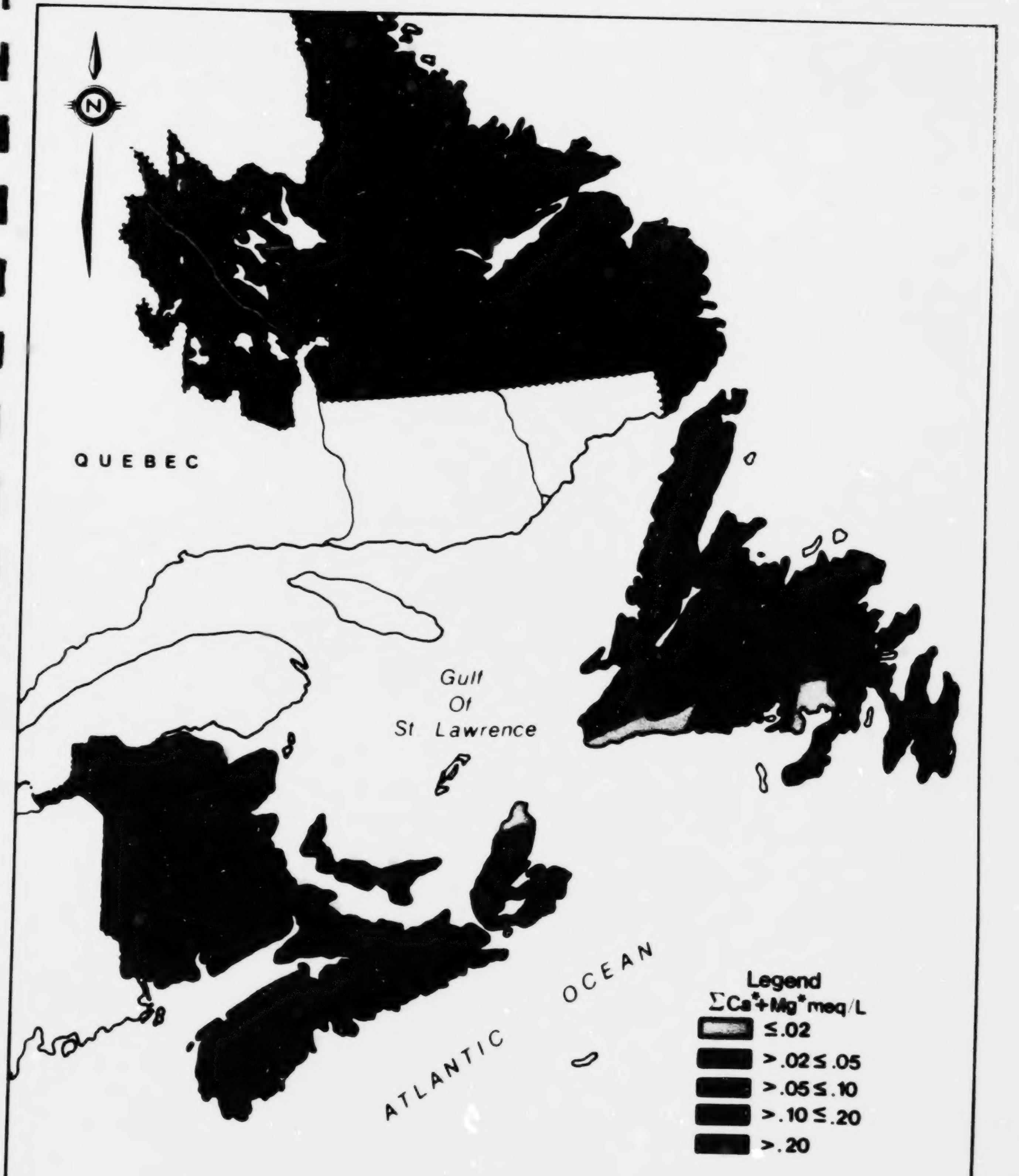

N
QUEBEC
Gulf
Of
St. Lawrence
ATLANTIC OCEAN
Legend
$\Sigma Ca^{+} + Mg^{+}$ meq/L
≤.02
>.02 ≤.05
>.05 ≤.10
>.10 ≤.20
>.20
SCALE
km 150
75
0
75
150 km

Plate 1

PLATE 2

A Regional Overview of Water Colour in
Atlantic Canada, based on Hydrometric
Basin Median Values

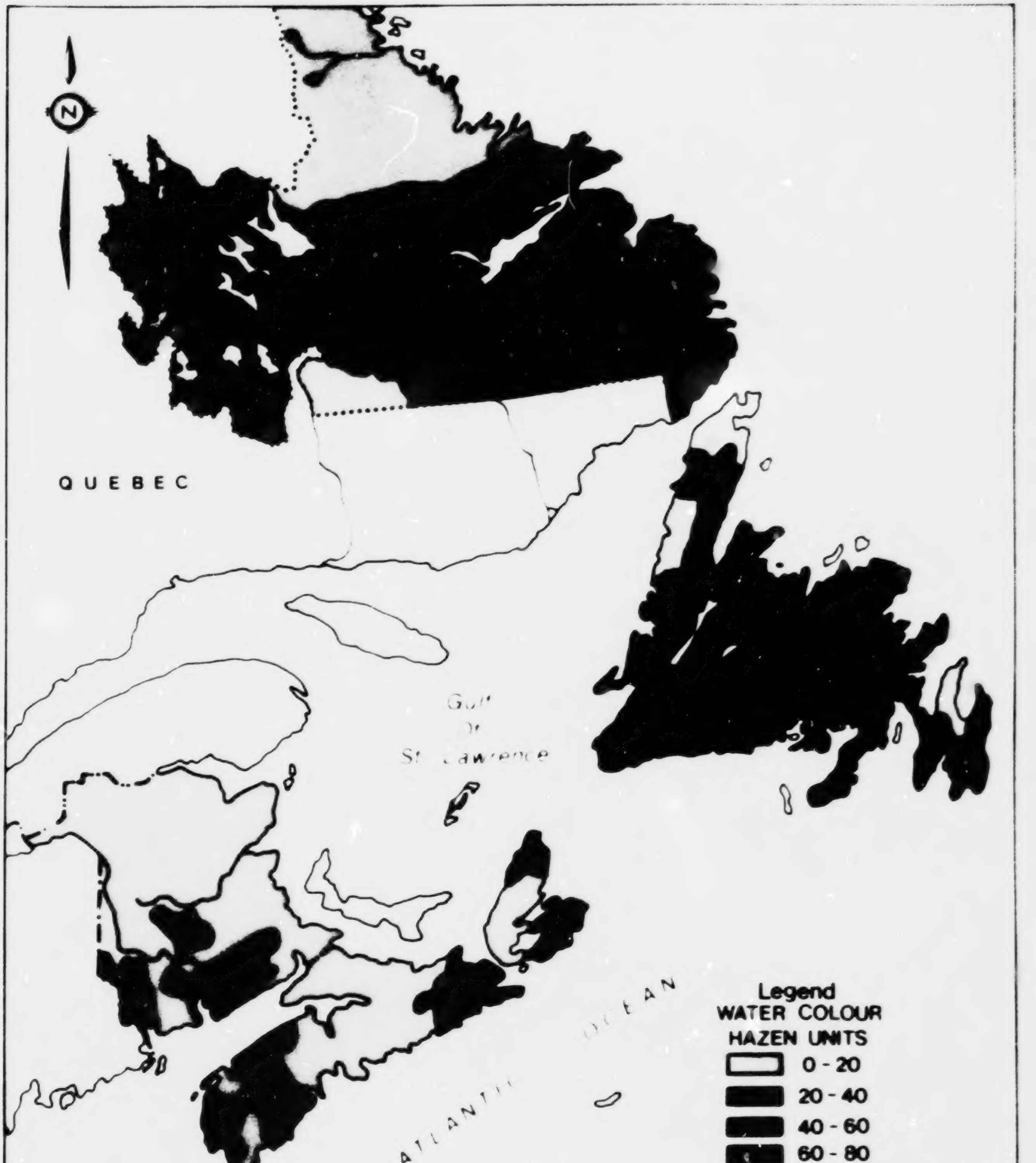

N
QUEBEC
Gulf
of
St. Lawrence
ATLANTIC OCEAN
Legend
WATER COLOUR
HAZEN UNITS
0 - 20
20 - 40
40 - 60
60 - 80
SCALE
km 150
75
0
75
150 km

Plate 2

PLATE 3

A Regional Overview of Excess Sulphate (IC) Concentrations in Atlantic Canada, based on Hydrometric Basin Median Values. Sulphate units are in ueq/L not meq/L

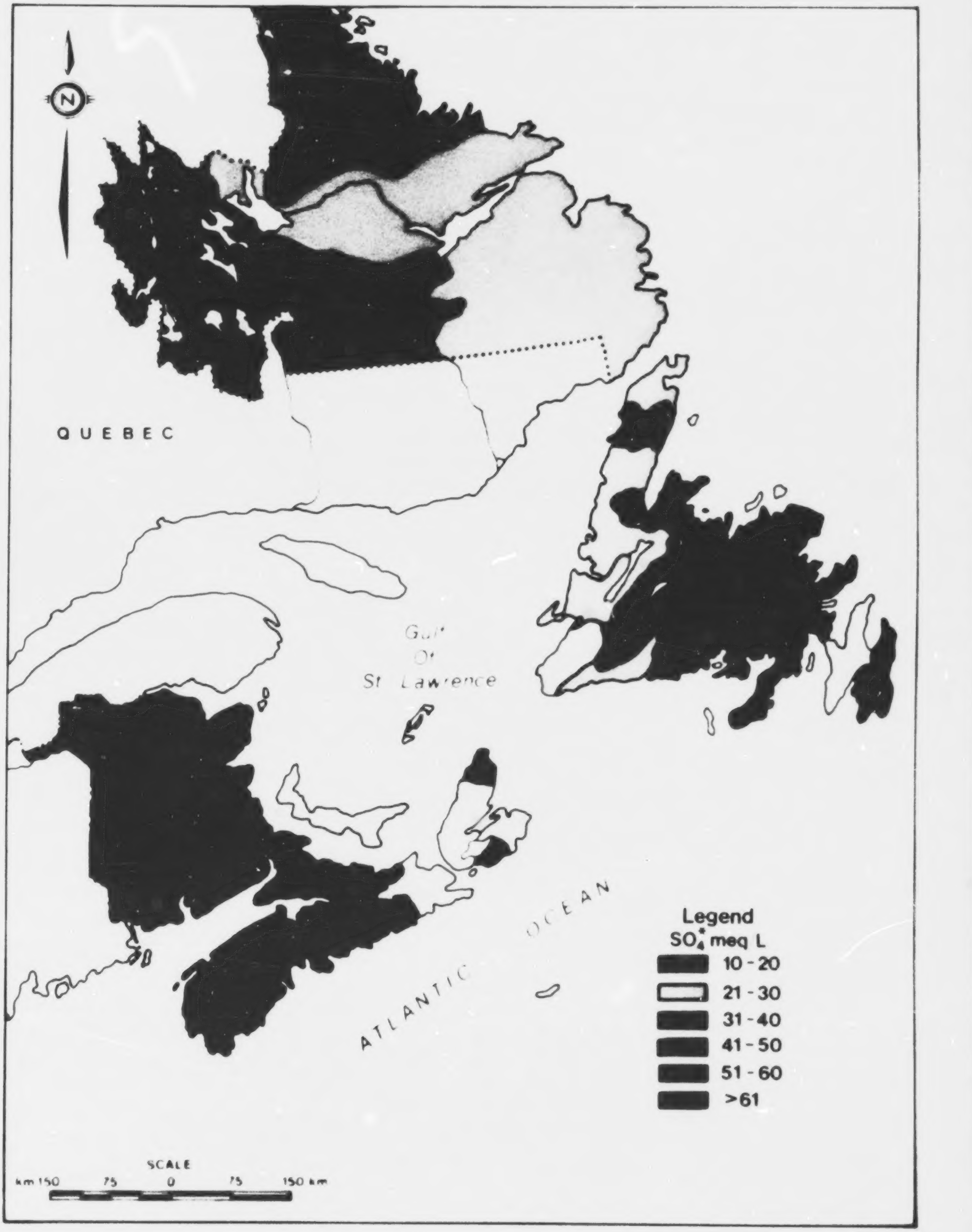

N
QUEBEC
Gulf
Of
St Lawrence
ATLANTIC OCEAN
Legend
SO$_4^*$ meq L
10 - 20
21 - 30
31 - 40
41 - 50
51 - 60
>61
SCALE
km 150
75
0
75
150 km

Plate 3

PLATE 4

A Regional Overview of Total Alkalinity Concentrations in Atlantic Canada, based on Hydrometric Basin Median Values

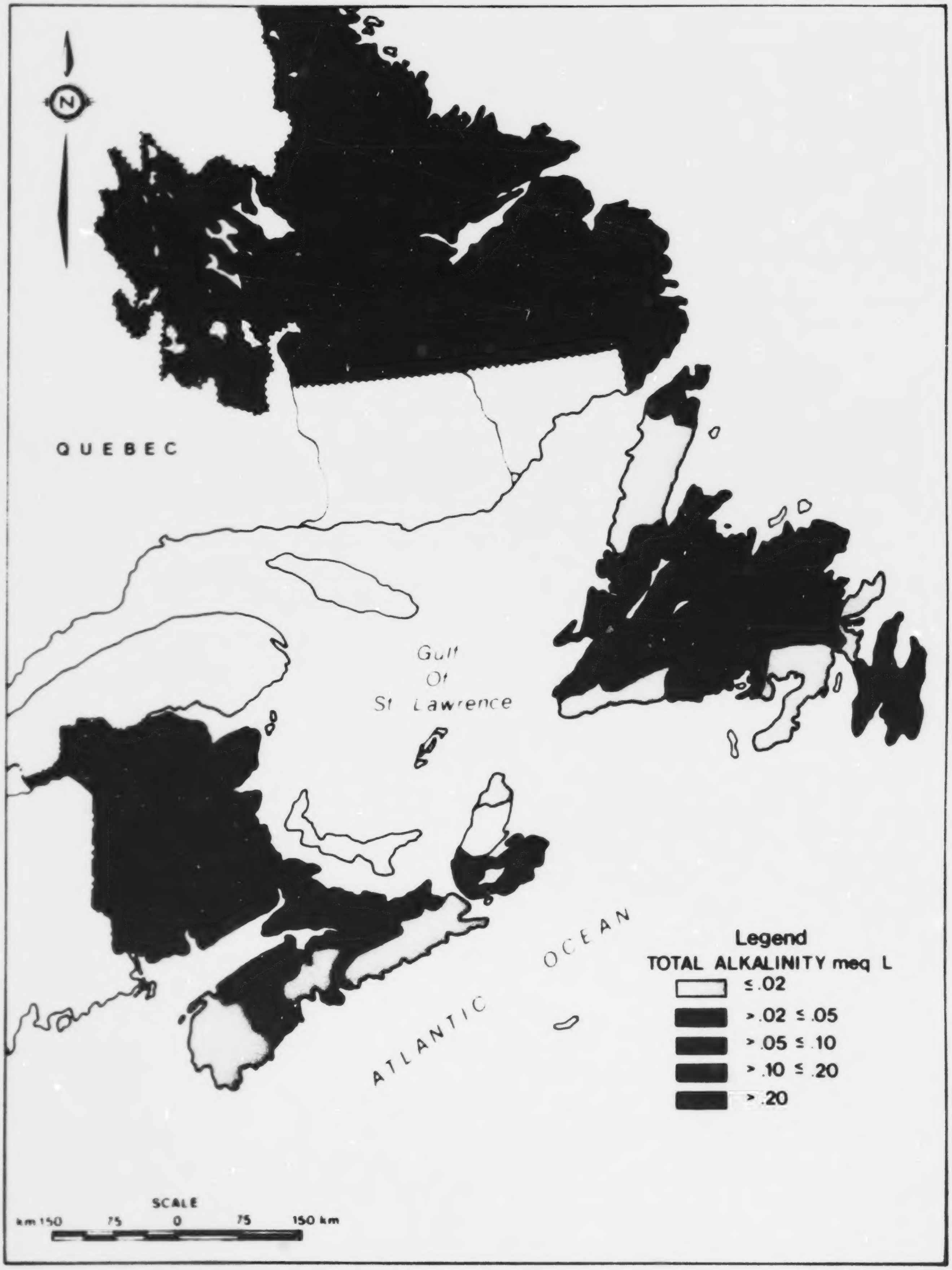

N
QUEBEC
Gulf
Of
St Lawrence
ATLANTIC OCEAN
Legend
TOTAL ALKALINITY meq L
≤ .02
> .02 ≤ .05
> .05 ≤ .10
> .10 ≤ .20
> .20
SCALE
km 150 75 0 75 150 km

Plate 4

PLATE 5

A Regional Overview of the Ratio of Total Alkalinity to Excess Calcium and Magnesium in Atlantic Canada, based on Hydrometric Basin Median Values

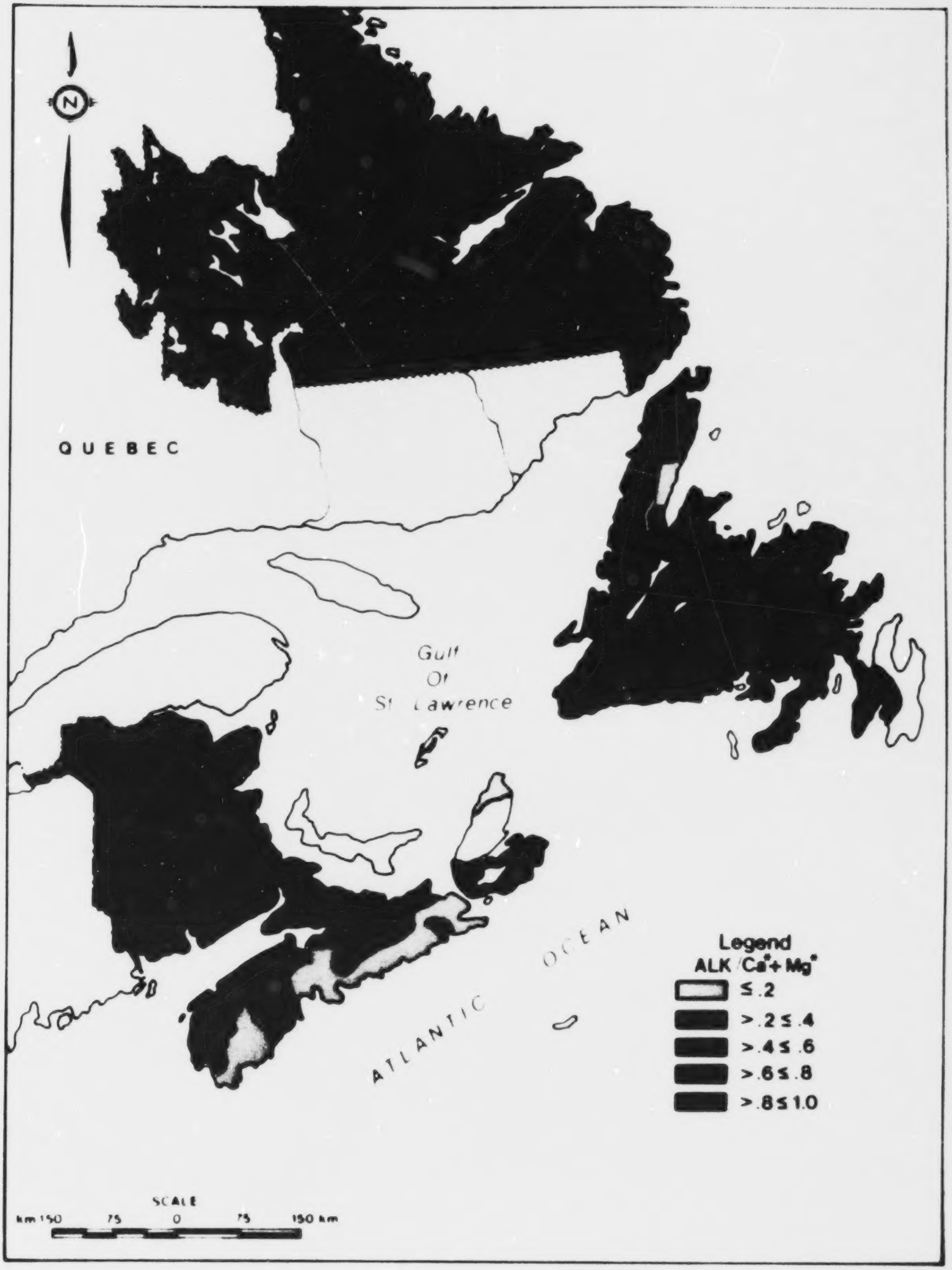

N
QUEBEC
Gulf
Of
St Lawrence
ATLANTIC OCEAN
Legend
ALK /Ca^{+}+ Mg^{+}
≤ .2
> .2 ≤ .4
> .4 ≤ .6
> .6 ≤ .8
> .8 ≤ 1.0
SCALE
km 150
75
0
75
150 km

Plate 5

PLATE 6

A Regional Overview of pH Values in
Atlantic Canada, based on Hydrometric
Basin Median Values

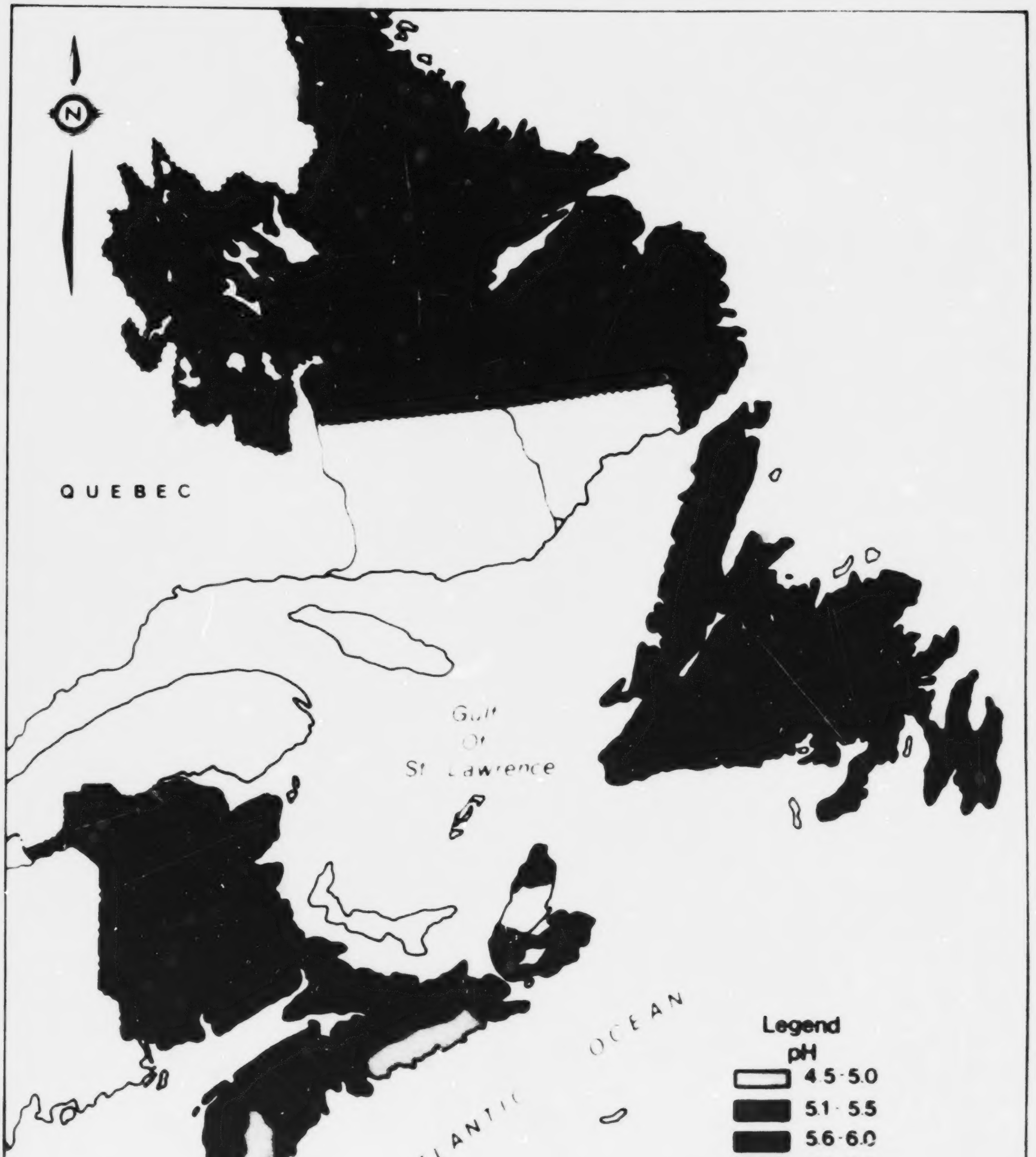

N
QUEBEC
Gulf
Of
St Lawrence
ATLANTIC OCEAN
Legend
pH
4.5-5.0
5.1-5.5
5.6-6.0
6.1-6.5
≥ 6.6
SCALE
km 150
75
0
75
150 km

Plate 6

13. LIST OF TABLES

Table 1: Hydrometric Basin Groupings for Nova Scotia Lake Stations

Table 2: Hydrometric Basin Groupings for Newfoundland Lake Stations

Table 3: Hydrometric Basin Groupings for New Brunswick River Stations

Table 4: Hydrometric Basin Groupings for Labrador Lake Stations

Table 5: A List of the Selected Water Quality Parameters and their Corresponding NAQUADAT Parameter Codes

Table 6: Factors Used to Correct Major Ion Concentrations for Marine Influence based on Chloride Concentration

Table 7: Factors Used to Calculate the Theoretical Specific Conductance

Table 8: A Breakdown of Lake Station Sampling Frequency for Nova Scotia, Newfoundland, Labrador and New Brunswick

Table 9: A Summary of the Characteristics of Major Geological Formations of Nova Scotia

Table 10: A Hydrometric Basin Breakdown of the Geological Structure of Nova Scotia

Table 11: A Summary of the Characteristics of Major Geological Formations of Insular Newfoundland

Table 12: A Hydrometric Basin Breakdown of the Geological Structure of Insular Newfoundland

Table 13: A Summary of the Characteristics of Major Geological Formations of New Brunswick

Table 14: A Hydrometric Basin Breakdown of the Geological Structure of New Brunswick

Table 15: A Summary of the Characteristics of Major Geological Formations of Labrador

Table 16: A Hydrometric Basin Breakdown of the Geological Structure of Labrador

Table 17: Comparison of Dissolved Sulphate and Total Sulphur as Sulphate Measured by Ion Chromatography

Table 18: Statistically Significant Year Effects for pH of Selected Newfoundland and Nova Scotia Rivers,

Controlling for Variation Due to River

TABLE 1: HYDROMETRIC BASIN GROUPINGS FOR NOVA SCOTIA LAKE STATIONS

Hydrometric Basin Code	Hydrometric Basin Groups
01DA	01DA
01DB	01DB
01DC	01DC
01DD	01DD
01EA	01EA
01EC	01EB, 01EC
01ED	01ED
01EE	01EE
01EF	01EF
01DE	01DE, 01EG, 01EH
01EJ	01EJ
01DG	01DG
01EK	01EK, 01EL, 01EM
01EN	01EN
01EO	01EO, 01EP, 01ER
01DH	01DH, 01DJ, 01DN, 01DS
01FD	01FB, 01FC, 01FD
01FH	01FH
01FJ	01FJ

TABLE 2: HYDROMETRIC BASIN GROUPINGS FOR NEWFOUNDLAND LAKE STATIONS

Hydrometric Basin Code	Hydrometric Basin Groups
02YA	02YA, 02YB
02YC	02YC, 02YD
02YE	02YE
02YF	02YF
02YH	02YH
02YK	02YK
02YL	02YL
02YM	02YM
02YN	02YN
01YO	02YO
02YP	02YP
02YQ	02YQ
02YR	02YR
02YS	02YS
02ZA	02ZA
02ZC	02ZB, 02ZC
02ZE	02ZD, 02ZE
02ZF	02ZF
02ZH	02ZG, 02ZH, 02ZJ
02ZK	02ZK
02ZL	02ZL
02ZM	02ZM, 02ZN

TABLE 3: HYDROMETRIC BASIN GROUPINGS FOR NEW BRUNSWICK RIVER STATIONS

Hydrometric Basin Code	Hydrometric Basin Groups
01AD	01AD
01AF	01AF
01AJ	01AJ, 01AL
01AP	01AM, 01AN, 01AP, 01AQ
01AR	01AR
01BJ	01BA, 01BB, 01BC, 01BE, 01BJ, 01BK
01BQ	01BO, 01BQ
01BT	01BV, 01BT, 01BU

TABLE 4: HYDROMETRIC BASIN GROUPINGS FOR LABRADOR LAKE STATIONS

Hydrometric Basic Code	Hydrometric Basin Groups
02WB	02YC, 02WB
02XA	02XA
02XB	02XB
02XC	02XC
03NG	03ND, 03NF, 03NG
03OE	03OA, 03OB, 03OC, 03OE
03PB	03PA, 03PB
03PC	03PC
03QC	03QA, 03QB, 03QC

TABLE 5: A LIST OF THE SELECTED WATER QUALITY PARAMETERS AND THEIR CORRESPONDING NAQUADAT PARAMETER CODES

PARAMETER	PARAMETER CODE
pH	10301
Specific Conductance	02041
Turbidity	02073
Water Colour	02011
Potassium	19103
Sodium	11103
Sulphate (Thorin; MTB; IC)	16303; 16304; 16309
Alkalinity (Total; Gran)	10101; 10110
Calcium	20110
Magnesium	12107
Chloride	17205
aluminium	13305
Iron	26304
Manganese	25304
DOC	06107
Nitrate:Nitrite	07110

TABLE 6: FACTORS USED TO CORRECT MAJOR ION CONCENTRATIONS FOR MARINE INFLUENCE BASED ON CHLORIDE CONCENTRATION

PARAMETER	FACTORS Concentration mg/L	 Concentration meq/L
Sodium	.556	.8579
Sulphate	.139	.1034
Calcium	.021	.0377
Magnesium	.067	.1943
Potassium	.020	.0183

TABLE 7: FACTORS USED TO CALCULATE THE THEORETICAL SPECIFIC CONDUCTANCE

PARAMETER	FACTOR
Bicarbonate	43.6
Calcium	52.0
Magnesium	46.6
Nitrate	71.0
Potassium	72.0
Sodium	49.0
Sulphate	74.0
Chloride	75.9
Hydrogen	347.0

TABLE 8: A BREAKDOWN OF LAKE STATION SAMPLING FREQUENCY FOR NOVA SCOTIA, NEWFOUNDLAND, LABRADOR AND NEW BRUNSWICK

	NUMBER OF SAMPLES														
	1	2	3	4	5	6	7	8	9	10	11-20	21-30	31-40	51-60	>100	Total
Nova Scotia	175	18	6	14	10	14	-	2	3	8	1	1	1	-	3	256
Newfoundland	270	23	5	9	11	10	2	1	-	3	1	-	-	-	-	335
Labrador	34	3	1	-	-	-	-	-	-	-	-	-	-	-	-	38
New Brunswick	27	2	-	-	10	-	-	-	-	-	1	-	-	1	-	41
Total	506	46	12	23	31	24	2	3	3	11	3	1	1	1	3	670

TABLE 9: A SUMMARY OF THE CHARACTERISTICS OF MAJOR GEOLOGICAL FORMATIONS OF NOVA SCOTIA

1 Cambrian - Quartzite, schist, gneiss, crystalline limestone

2 Cambrian - Quartzite, schist, gneiss, limestone with intruded granites

3 Cambrian - Volcanic brecchia, tuff, lava, greywacke, shale and schist

4 Cambrian - Shale, greywacke, volcanic rocks, sandstone, conglomerate

5 Ordovician - Goldenville formation - greywacke, quartzite, gneiss, minor slate

6 Ordovician - Halifax formation - slate, schist, minor quartzite

7 Ordovician - Greywacke, sandstone, conglomerate, volcanic rocks, schist

8 Silurian - quartzite, slate, shale, siltstone, volcanic rocks

9 Silurian - shale, sandstone, limestone

10 Silurian - Undivided sedimentary rocks, mudstone and shale

11 Silurian - Sandstone, conglomerate, quartzite

12 Devonian - Shale, quartzite, minor limestone, iron formation

13 Devonian - Dioritic and gabbroic rocks

14 Devonian - Granitic and allied rocks

15 Devonian - Conglomerate, arkose, shale, tuff

16 Mississippian - Horton group - sandstone, shale, conglomerate, arkose

17 Mississippian - Windsor group - limestone, gypsum, anhydorite, shale, sandstone, salt, conglomerate

18 Mississippian - Canso group - shale, sandstone, conglomerate, limestone

19 Pennsylvanian - Conglomerate, sandstone, shale, coal, limestone

20 Pennsylvanian - Conglomerate, sandstone, shale, coal, limestone

21 Pennsylvanian - Conglomerate, sandstone, shale, coal, limestone

22 Pennsylvanian - Gabbro, diabasic gabbro, rhyslite

23 Annapolis - Conglomerate, sandstone, shale

24 Triassic - basalt, diabase

TABLE 10:A HYDROMETRIC BASIN BREAKDOWN OF THE GEOLOGICAL STRUCTURE OF NOVA SCOTIA.

GEOLOGICAL FORMATION	DA	DB	DC	DD	EA	EB EC	ED	EE	EF	DE EG EH	EJ	DG	EK EL EM	EN	ED EP ER	DH DJ DN DS	FB FC FD	FH	FJ
1																	+		+
2																	+		
3																		+	+
4																		+	
5	+	+		+	+	+	+	+	+	+	+	+	+	+	+		+		
6	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+				
7															+				
8	+	+	+	+	+														
9																+			
10																+			
11																		+	+
12		+	+																
13															+		+		+
14		+	+		+	+	+	+	+	+	+	+	+		+	+	+	+	+
15															+		+		
16				+						+		+				+	+	+	+
17										+		+	+		+	+	+	+	+
18												+			+	+	+	+	
19												+				+	+	+	
20																+			
21															+	+		+	+
22																			
23		+	+	+											+	+			
24		+	+	+												+			

** SEE TABLE 9 FOR DESCRIPTIONS OF GEOLOGICAL FORMATION CODES.

TABLE 11: A SUMMARY OF THE CHARACTERISTICS OF MAJOR GEOLOGICAL FORMATIONS OF INSULAR NEWFOUNDLAND

1 Long Range Complex - Anorthosite, gabbroic anorthosite, gabbro and related rocks

2 Long Range Complex - Massive to foliated granitic rocks

3 Holyrood plutonic series - Quartz diorite, diorite, gabbro, monzonite

4 Holyrood plutonic series - Granodiorite, quartz monzonite, granite, quartz diorite

5 Lower Cambrian - Diabase dykes

6 Devonian - Peridotite, serpentinized peridotite, altered pyroxenite, dienite, mafic to ultra mafic rocks

7 Devonian - Gabbro, diorite, pyroxenite, quartz diorite, granodiorite, mafic syenite and related rocks

8 Devonian - Granite, granodiorite, syenite, monzonite, quartz diorite and related rocks

9 Helikian - Quartzo-feldspathic gneiss and schist, amphibolite and unseparated intrusions

10 Cambrian - Psammitic to pelitic gneiss and schist, marble, quartzite, amphibolite, unseparated intrusions

11 Cambrian - Limestone, quartzite, shale, dolomite, slate, arkose, conglomerate and basalt

12 Ordovician - Limestone, dolomite, quartzite, sandstone and shale

13 Silurian - Sandstone, conglomerate, acidic to mafic rocks, greywacke, shale, limestone

14 Lower Devonian - Shale, sandstone, conglomerate, and metamorphic equivalent

15 Upper Devonian - Conglomerate, arkose, acidic volcanic rocks

16 Carboniferous - Conglomerate, sandstone, siltstone, shale, limestone, gypsum and coal

17 Ordovician - Intermediate to mafic volcanic rocks, slate, greywacke, siltstone, chert, conglomerate, minor limestone

18 Ordovician - Siltstone quartzite, slate, greywacke, and

metamorphic equivalents

19 Ordovician - Shale, siltstone, sandstone, hematite beds

20 Cambrian - Shale with limestone, conglomerate, siltstone, sandstone, volcanic rock and manganese beds

21 Hadrynian - Quartzite, conglomerate, siltstone, and arkose

22 Hadrynian - Siltstone, arkose, conglomerate, slate, acidic to intermediate volcanic rocks

23 Hadrynian - Slate, siltstone, greywacke, conglomerate and minor volcanic rocks

24 Hadrynian - Acidic to mafic volcanic rocks, slate, greywacke, conglomerate

25 Ordovician - Sandstone, limestone, shale and conglomerate

26 Cambrian - Shale, sandstone, slate, greywacke, limestone, conglomerate and basic volcanic rocks

27 Ordovician - Slate, greywacke, acidic to mafic volcanic rocks, quartzite, chert and limestone

28 Ordovician - Sandstone, slate, greywacke, conglomerate, acidic to mafic volcanic rocks

29 Hadrynian - Acidic to mafic volcanic rocks, slate, siltstone, greywacke and conglomerate

TABLE 12:A HYDROMETRIC BASIN BREAKDOWN OF THE GEOLOGICAL STRUCTURE OF INSULAR NEWFOUNDLAND

GEOLOGICAL FORMATION	YA YB	YC YD	YE	YF	YH	YK	YL	YM	YN	YO	YR	YS	ZA ZB	ZC ZD	ZE	ZF	ZG ZH	ZK	ZL	ZM ZN
1													+							
2		+	+	+																
3																			+	+
4																				+
5		+		+																
6	+				+	+		+		+		+	+							
7					+	+		+	+	+			+	+	+	+	+	+		
8						+	+	+	+	+	+	+	+	+	+	+	+			
9		+	+	+	+		+													
10						+	+	+												
11	+	+			+	+	+													
12	+	+	+		+	+	+													
13						+		+	+	+				+	+	+	+			
14													+							
15										+						+				
16						+	+		+				+							
17								+	+	+		+		+	+	+				
18											+				+	+				
19																				+
20															+	+	+	+	+	+
21																				
22												+					+	+	+	+
23												+					+	+	+	+
24											+	+					+		+	+
25																			+	
26	+		+		+		+													
27						+			+	+			+	+						
28									+				+	+						
29																	+			

** SEE TABLE 11 FOR DESCRIPTIONS OF GEOLOGICAL FORMATION CODES.

TABLE 13: A SUMMARY OF THE CHARACTERISTICS OF MAJOR GEOLOGICAL FORMATIONS OF NEW BRUNSWICK

1 Triassic - Mafic volcanic flows; sills and dykes

2 Triassic - Red to grey conglomerate, sandstone, shale

3 Pennsylvanian - Red to grey sandstone, conglomerate, siltstone

4 Mississippian - Red to grey conglomerate, siltstone

5 Mississippian - Limestone, gypsum, shale, sandstone

6 Mississippian - Silicic volcanic flows, tuffs and intrusive rocks

7 Mississippian - Red to grey sandstone, conglomerate, shale and minor limestone

8 Devonian - granite, quartz monzonite, granodiorite, and related rocks

9 Devonian - Gabbro, diabase, diorite

10 Devonian - granite and dioritic rocks

11 Devonian - shale, limestone, sandstone, minor greywacke, tuff and volcanic rocks

12 Silurian - Greywacke, slate, conglomerate, sandstone and volcanic rocks

13 Silurian - Greywacke, slate, siltstone, sandstone, conglomerate and limestone

14 Ordovician - Peridotite and gabbro

15 Ordovician - Calcareous and argillaceous sedimentary rocks

16 Ordovician - Mafic volcanic rocks; dykes or sills

17 Ordovician - Silicic volcanic rocks, rhyolite, rhyolite - porphyry

18 Ordovician - Silicic tulfaceous rocks, quartz-feldspar augen schist

19 Ordovician - Mafic volcanic flows, dykes and sills

20 Ordovician - Argillaceous sedimentary rocks, greywacke, quartzite, conglomerate, chert and limestone

21 Cambrian - granite, granodiorite, quartz diorite, gabbro rocks

22 Precambrian - granite, granodiorite, quartz diorite, gabbro rocks

23 Precambrian - Sedimentary and volcanic rocks, metamorphosed equivalents

24 Precambrian - Limestone, quartzite, argillite, dolomite, conglomerate

TABLE 14:A HYDROMETRIC BASIN BREAKDOWN OF THE GEOLOGICAL STRUCTURE OF NEW BRUNSWICK

GEOLOGICAL FORMATION	AD	AF	AG,AJ AL	AM,AN AP,AQ	AR	BA,BB,BC BE,BJ,BK	BO,BQ	BV,BT,BU
1								
2					+			
3			+	+	+	+	+	+
4			+					+
5								+
6				+				+
7			+	+				
8			+	+	+	+	+	
9					+	+	+	
10			+	+	+		+	
11	+	+			+	+		
12			+		+	+		
13		+	+	+	+			
14								
15		+	+	+	+	+		+
16								
17						+	+	
18							+	
19							+	
20			+	+	+		+	
21								+
22				+				+
23				+	+			+
24				+				+

** SEE TABLE 13 FOR DESCRIPTIONS OF GEOLOGICAL FORMATION CODES.

TABLE 15: A SUMMARY OF THE CHARACTERISTICS OF MAJOR GEOLOGICAL FORMATIONS OF LABRADOR

1 Archean - pyroxene - bearing gran odiorite and syenodiorite

2 Archean - massive granite and quartz monzonite

3 Aphebian - amorthosite, amphibolite, feldspar gneiss

4 Aphebian - foliated granodiorite and granodiorite gneiss

5 Aphebian - foliated feldspar, quartz, hornblend, granitic gneiss, amphibolite

6 Aphebian - gabbro, metagabbro, glowero porphyritic gabbro and diorite

7 Aphebian - granite, quartz monzonite, granodiorite, quartz diorite

8 Aphebian - syenite, monzonite, syenodiorite

9 Paleohelikian - granite to granodiorite

10 Paleohelikian - gabbro, norite, anorthositic gabbro, tractolite, diorite, gneiss, amphibolite

11 Paleohelikian - anorthosite, gabbro, monzonite, granodiorite, fernosyenite

12 Paleohelikian - troclolite, gabbro, anorthosite, pyroxenite, ferrosyenite

13 Paleohelikian - adomellite, monzonite, syenite, granodiorite, granite

14 Paleohelikian - granite, quartz monzonite, granodiorite, quartz diorite, syenite

15 Neohelikian - granite to granodiorite, granitic gneiss, minor ayenite rocks

16 Neohelikian - gabbro, norite, diabase sills

17 Neohelikian - diabasic gabbro, intermediate and ultramofic intrusive rocks

18 Cambrian - diabasic dykes

19 Aphebian - granitoid gneisses, amphibolite, metaquartzite, marble, granulitic

20 Helikian - granitic gneiss, quartzite, amphibolite, mignatatic, marble, feldspathic gneiss

21 Helikian - quartzite, conglomerate, arkose, shale, basalt, greenstone, chlorite schist, limestone, slate

22 Aphebian - basaltic flows, conglomerates, greywacke, slate, argillite, arkose, delomite, limestone, quartzite

23 Aphebian - granulite, granitic gneiss, amphibolite, migmalite, quartzite, marble, chlorite, schist

24 Archean - granitic gneiss, amphibolite, granulite, greenston, migmatite, ultrabasic intrusions

25 Hadrynian - red conglomerate, arkose, siltstone

26 Hadrynian - red conglomerate, arkose, sandstone, shale

27 Cambrian - conglomerate, quartzite, arkose, shale, limestone, chert, siltstone, mafic volcanic rocks

28 Triassic - andesitic volcanics and shallow intrusions

TABLE 16:A HYDROMETRIC BASIN BREAKDOWN OF THE GEOLOGICAL STRUCTURE OF LABRADOR

GEOLOGICAL FORMATION	VC	WB	XA	XB	XC	ND NF NG	OA OB OE OC	PA	PB	PC	QB	QC
1							+					
2							+					
3												
4												
5						+				+		
6						+	+					
7						+				+		
8						+						
9												
10	+		+				+	+			+	
11	+					+		+			+	
12						+						
13			+		+	+	+	+			+	
14						+		+				
15	+		+	+	+		+			+	+	
16										+		
17								+				
18								+				
19							+					
20	+		+	+	+		+	+		+	+	
21						+		+				
22						+						
23						+	+	+				
24						+	+					
25						+						
26							+				+	
27												
28												

**SEE TABLE 15 FOR DESCRIPTIONS OF GEOLOGICAL FORMATION CODES.

TABLE 17: COMPARISON OF DISSOLVED SULPHATE (mg/l) AND TOTAL SULPHUR (AS SULPHATE) MEASURED BY ION CHROMATOGRAPHY.

STATION	DATE	WATER COLOUR H. U.	SULPHATE MTB MG/L	SULPHATE IC MG/L	SULPHUR (BY IC) AS SULPHUR
UPPER INDIAN	JUNE 1986	35	1.7	0.9	2.1
MIDDLE ARM	JUNE 1986	45	1.7	1.0	2.2
NEAR BUCHANS	JUNE 1986	30	1.9		2.2
BURLINGTON	JUNE 1986	120	3.3	0.6	1.6
RATTLE	JUNE 1986	25	1.8		1.8
OCHRE HILL	JUNE 1986	70	2.0	1.1	2.5
BOG POND	JUNE 1986	25	1.1		2.0
LONG WATERS	JUNE 1986	35	1.4	1.0	2.1

TABLE 18: STATISTICALLY SIGNIFICANT YEAR EFFECTS FOR pH OF SELECTED NEWFOUNDLAND AND NOVA SCOTIA RIVERS, CONTROLLING FOR VARIATION DUE TO RIVER

					1965					1970					1975					1980				
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
pH	N.S.	yr	.001	.98							-.18	-.24		.29			.60							.13
		sp	.05	.95																				
		su	.001	.97					-.25	-.31	-.41						-.40				-.30			
		wi	.05	.93								-.43												
	Nfld	yr	.001	.88					-.27		-.30	-.34	-.23											
		sp	.001	.81			-.31	-.40	-.24	-.35	-.22	-.34	.27											
		su	.001	.68							-.42													
		wi	.001	.73						-.31	-.70	-.32												

14. List of Figures

Figure 1: The Distribution of Lake Stations in Nova Scotia

Figure 2: The Distribution of Lake Stations in Insular Newfoundland

Figure 3: The Distribution of Lake Stations in Labrador

Figure 4: The Distribution of Lake Stations in New Brunswick

Figure 5: Relationship between Measured and Calculated Specific Conductance for Lakes in Atlantic Canada

Figure 6: The Ratio of Total Dissolved Salts to Specific Conductance for Lakes in Atlantic Canada

Figure 7: Relationship between Measured and Calculated Specific Conductance for Rivers in Atlantic Canada

Figure 8: The Ratio of Total Dissolved Salts to Specific Conductance for Rivers in Atlantic Canada

Figure 9: A map of the general geological structure of Nova Scotia

Figure 10: A map of the general geological structure of Insular Newfoundland

Figure 11: A map of the general geological structure of New Brunswick

Figure 12: A map of the general geological structure of Labrador

Figure 13: Annual mean precipitation pH values for selected Atlantic Canada monitoring sites

Figure 14: Annual excess wet sulphate deposition values for selected Atlantic Canada monitoring sites

Figure 15: Histograms of the sum of excess calcium and magnesium concentrations for lakes and rivers in the Atlantic provinces

Figure 16: Boxplot of the sum of excess calcium and magnesium concentration for lakes in selected Nova Scotia Hydrometric Basins

Figure 17: Boxplot of the sum of excess calcium and magnesium concentration for lakes in selected Newfoundland Hydrometric Basins

Figure 18: Boxplot of the sum of excess calcium and magnesium concentration for lakes in selected Labrador Hydrometric Basins

Figure 19: Boxplot of the sum of excess calcium and magnesium concentration for lakes in selected New Brunswick Hydrometric Basins

Figure 20: Boxplot of the sum of excess calcium and magnesium concentration for Rivers in selected New Brunswick Hydrometric Basins

Figure 21: Histograms of dissolved organic carbon concentrations for lakes and rivers in the Atlantic provinces

Figure 22: Histograms of water colour for lakes and rivers in the Atlantic provinces

Figure 23: Boxplot of dissolved organic carbon concentration for lakes in selected Nova Scotia Hydrometric Basins

Figure 24: Boxplot of water colour for lakes in selected Nova Scotia Hydrometric Basins

Figure 25: Boxplot of Dissolved Organic carbon concentrations for lakes in selected Newfoundland Hydrometric Basins

Figure 26: Boxplot of water colour for lakes in selected Newfoundland Hydrometric Basins

Figure 27: Boxplot of dissolved organic carbon concentration for lakes in selected Labrador Hydrometric Basins

Figure 28: Boxplot of water colour for lakes in selected Labrador Hydrometric Basins

Figure 29: Boxplot of dissolved organic carbon concentration for rivers in selected New Brunswick Hydrometric Basins

Figure 30: Boxplot of water colour for rivers in selected New Brunswick Hydrometric Basins

Figure 31: Histograms of excess ion chromatograph sulphate concentrations for lakes and rivers in the Atlantic provinces

Figure 32: Histograms of excess MTB sulphate concentrations for lakes and rivers in the Atlantic provinces which have water colours less than or equal to 30

Figure 33: Boxplot of excess sulphate (IC) concentration for lakes in selected Nova Scotia Hydrometric Basins

Figure 34: Boxplot of excess sulphate (MTB) concentration for lakes in selected Newfoundland Hydrometric Basins which have water colours less than or equal to 30.

Figure 35: Boxplot of excess sulphate (MTB) concentration for lakes in selected Newfoundland Hydrometric Basins

Figure 36: Boxplot of excess sulphate (IC) concentration for rivers in selected New Brunswick Hydrometric Basins

Figure 37: Boxplot of excess sulphate (MTB) concentration for lakes in selected Labrador Hydrometric Basins which have water colours less than or equal to 30.

Figure 38: Boxplot of excess sulphate (MTB) concentration for lakes in selected Nova Scotia Hydrometric Basins

Figure 39: Boxplot of excess sulphate (MTB) concentration for lakes in selected Labrador Hydrometric Basins

Figure 40: Boxplot of excess sulphate (MTB) concentration for rivers in selected New Brunswick Hydrometric Basins

Figure 41: Histograms of the Total Alkalinity concentrations for lakes in the Atlantic provinces

Figure 42: Histogram of the total alkalinity concentrations for rivers in New Brunswick

Figure 43: Boxplot of total alkalinity concentrations for lakes in selected Nova Scotia Hydrometric Basins

Figure 44: Boxplot of Alkalinity deficit for lakes in selected Nova Scotia Hydrometric Basins

Figure 45: Boxplot of the ratio of alkalinity to excess calcium and magnesium for lakes in selected Nova Scotia Hydrometric Basins

Figure 46: Boxplot of total alkalinity concentration for lakes in selected Newfoundland Hydrometric Basins

Figure 47: Boxplot of alkalinity deficit for lakes in selected Newfoundland Hydrometric Basins

Figure 48: Boxplot of the ratio of alkalinity to excess calcium and magnesium for lakes in selected Newfoundland Hydrometric Basins

Figure 49: Boxplot of total alkalinity concentrations for lakes in selected Labrador Hydrometric Basins

Figure 50: Boxplot of alkalinity deficit for lakes in selected Labrador Hydrometric Basins

Figure 51: Boxplot of the ratio of alkalinity to excess calcium and magnesium for lakes in selected Labrador Hydrometric Basins

Figure 52: Boxplot of total alkalinity concentration for rivers in selected New Brunswick Hydrometric Basins

Figure 53: Boxplot of alkalinity deficit for rivers in selected New Brunswick Hydrometric Basins

Figure 54: Boxplot of the ratio of alkalinity to excess calcium and magnesium for rivers in selected New Brunswick Hydrometric Basins

Figure 55: Relationship between pH and Alkalinity for Selected Lakes in Nova Scotia

Figure 56: Histograms of pH for lakes and rivers in the Atlantic provinces

Figure 57: Cumulative probability plots of pH in lakes and rivers in the Atlantic provinces

Figure 58: Boxplot of pH for lakes in selected Nova Scotia Hydrometric Basins

Figure 59: Histograms of pH for lakes in four southwestern Nova Scotia Hydrometric Basins

Figure 60: Histograms of pH for lakes in four Nova Scotia

Hydrometric Basins located near Halifax

Figure 61: Boxplot of pH for lakes in selected Newfoundland Hydrometric Basins

Figure 62: Boxplot of pH for lakes in selected Labrador Hydrometric Basins

Figure 63: Boxplot of pH for rivers in selected New Brunswick Hydrometric Basins

Figure 64: Histograms of extractable aluminium concentrations for lakes in the Atlantic provinces

Figure 65: Boxplot of extractable aluminium concentration for lakes in selected Nova Scotia Hydrometric Basins

Figure 66: Relationship between extractable aluminium and dissolved organic carbon concentration for four Nova Scotia Hydrometric Basins

Figure 67: Boxplot of extractable aluminium concentrations for lakes in selected Newfoundland Hydrometric Basins

Figure 68: Boxplot of extractable aluminium concentrations for lakes in selected Labrador Hydrometric Basins

Figure 69: Boxplot of extractable aluminium concentrations for lakes in selected New Brunswick Hydrometric Basins

Figure 70: Boxplot of the organic anion corrected alkalinity to excess calcium and magnesium ratio for lakes in selected Nova Scotia Hydrometric Basins

Figure 71: Boxplot of the reactive organic anion corrected alkalinity to excess calcium and magnesium ratio for lakes in selected Nova Scotia Hydrometric Basins

Figure 72a,b,c: Application of the Nova Scotia Hydrometric Basin 01EA Data to the Henriksen models

Figure 73a,b,c: Application of the Nova Scotia Hydrometric Basin 01ED data to the Henriksen models

Figure 74a,b,c: Application of the Nova Scotia Hydrometric Basin 01FD data to the Henriksen models

Figure 75a,b,c: Application of the Nova Scotia Hydrometric Basin 01EJ data to the Henriksen models

Figure 76a,b,c: Application of the New Brunswick lake data to the Henriksen models

Figure 77a,b,c: Application of the Newfoundland Great Northern

Peninsula Hydrometric Basin data to the Henriksen models

Figure 78a,b,c: Application of the Newfoundland South Coast Hydrometric Basin data to the Henriksen models

Figure 79a,b: Application of the Southern Labrador Hydrometric Basin data to the Henriksen models

Figure 80a,b: Application of the Central and Northern Labrador Hydrometric Basin data to the Henriksen models

Figure 81: Running boxplots of pH for selected Nova Scotia and Newfoundland rivers from 1965 to 1985

Figure 82: Plots of the fitted yearly pH values from the ANOVA models for the Nova Scotia and Newfoundland rivers

Figure 83: Temporal changes in SO_2 Emissions in Eastern Canada and the USA

Figure 84a: Temporal changes in Hydrogen Ion Export for the Isle aux Morts river calculated with Daily Mean Discharge values

Figure 84b: Temporal changes in Hydrogen Ion Export for the Isle aux Morts river calculated with Monthly Mean Discharge values

Figure 85a: Temporal changes in Hydrogen Ion Export for the Piper's Hole river calculated with Daily Mean Discharge values

Figure 85b: Temporal changes in Hydrogen Ion Export for the Piper's Hole river calculated with Monthly Mean Discharge values

Figure 86a,b: Temporal variations of sulphate concentrations for two rivers in Atlantic Canada

Figure 87a,b: Temporal changes in excess Sulphate Ion Export for the Isle aux Morts river calculated with Daily Mean Discharge values

Figure 88a,b: Temporal changes in excess Sulphate Ion Export for the Isle aux Morts river calculated with Monthly Mean Discharge values

Figure 89a,b: Temporal changes in Excess Sulphate Ion Export for the Wallace river calculated with Daily Mean Discharge values

Figure 90a,b: Temporal changes in Excess Sulphate Ion Export for the Wallace river calculated with Monthly Mean Discharge values

Figure 91: Running boxplots of extractable aluminium and dissolved organic carbon concentrations for selected rivers in Atlantic Canada

Figure 1. The Distribution of Lake Stations in Nova Scotia.

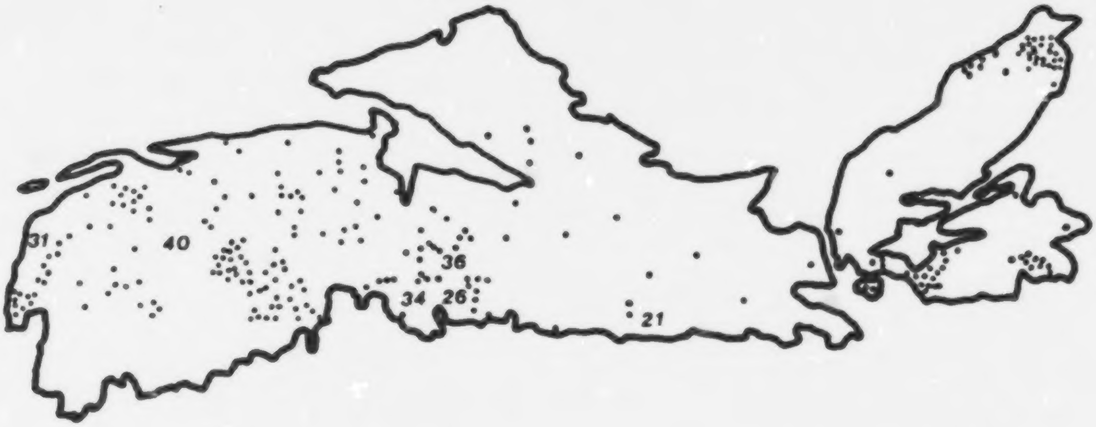

31
40
36
34
26
21

Figure 2. The Distribution of Lake Stations in Insular Newfoundland.

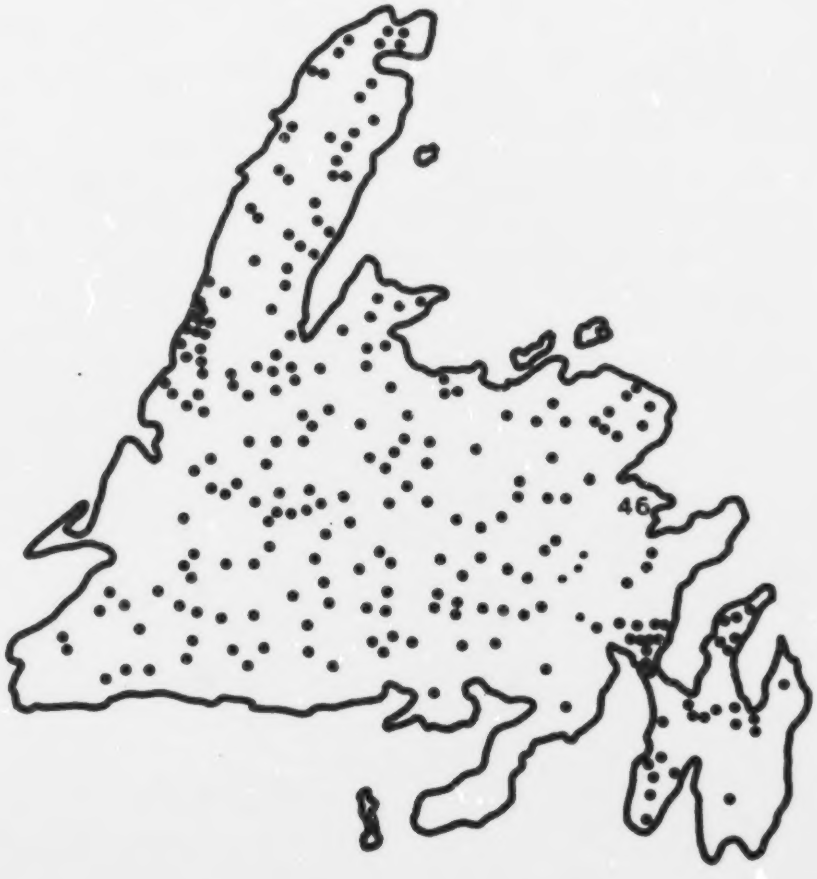


Figure 3. Distribution of Lake Stations in Labrador.

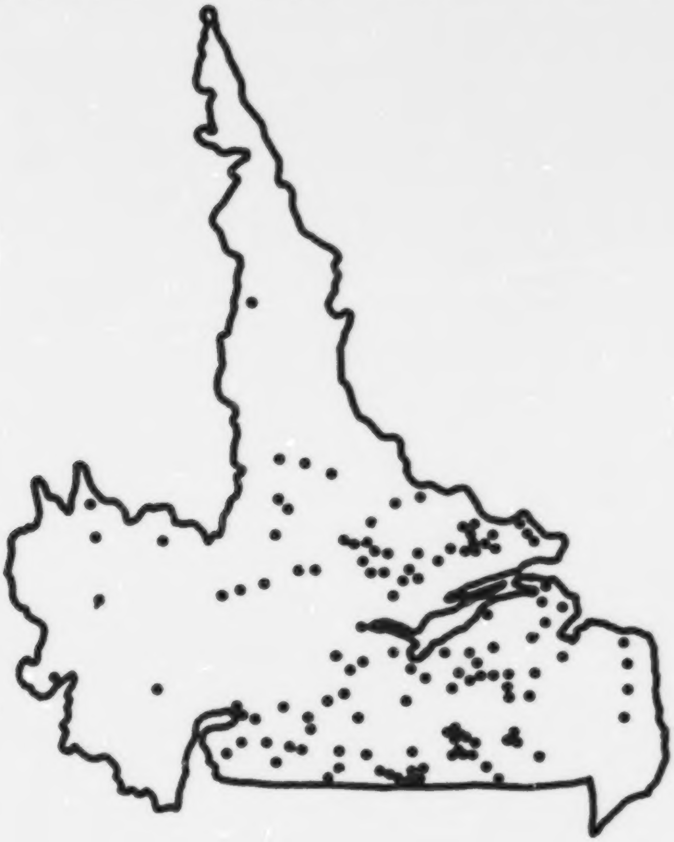


Figure 4. Distribution of River Stations in New Brunswick.

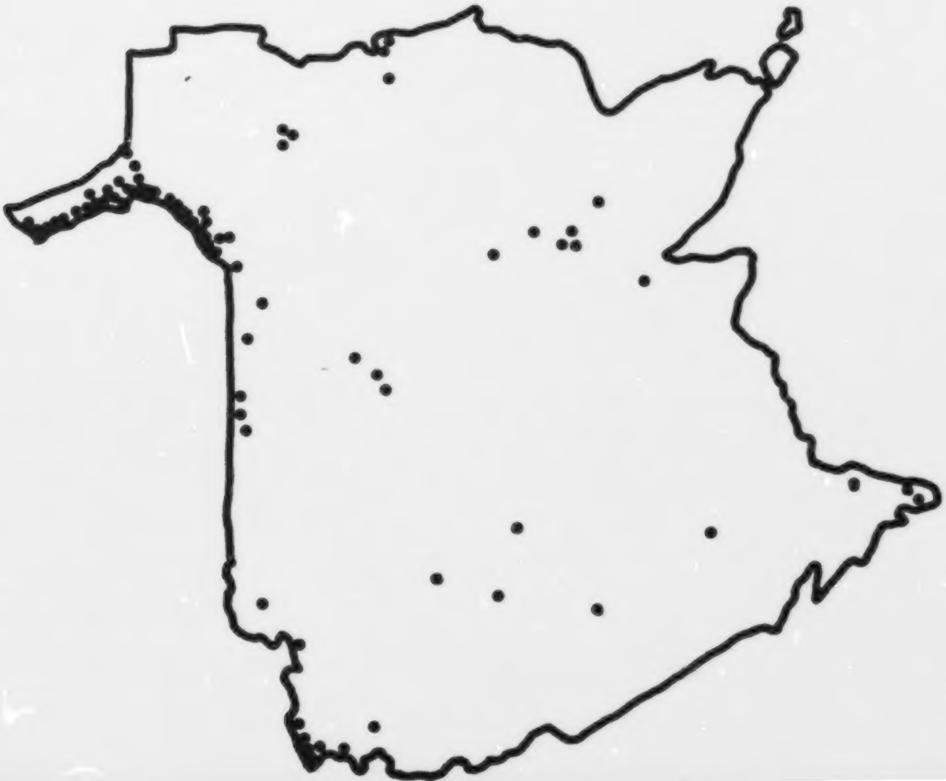
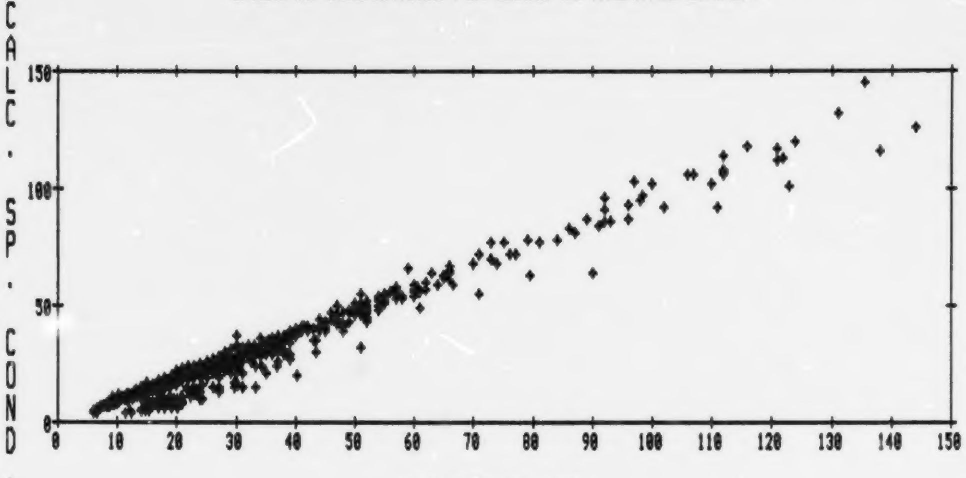
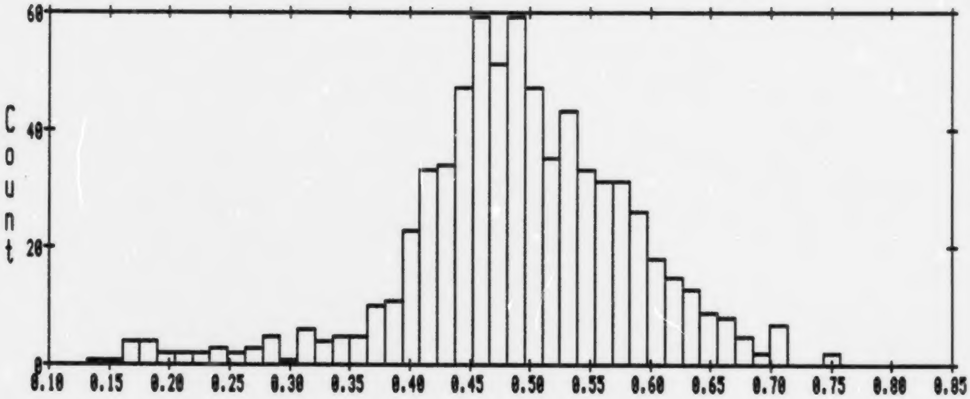


FIGURE 5: RELATIONSHIP BETWEEN MEASURED AND CALCULATED SPECIFIC CONDUCTANCE FOR LAKES IN ATLANTIC CANADA.



MEASURED SP. COND.

FIGURE 6: THE RATIO OF TOTAL DISSOLVED SALTS TO SPECIFIC CONDUCTANCE FOR LAKES IN ATLANTIC CANADA



TDS/SP. COND

FIGURE 7: RELATIONSHIP BETWEEN MEASURED AND CALCULATED SPECIFIC CONDUCTANCE FOR RIVERS IN ATLANTIC CANADA.

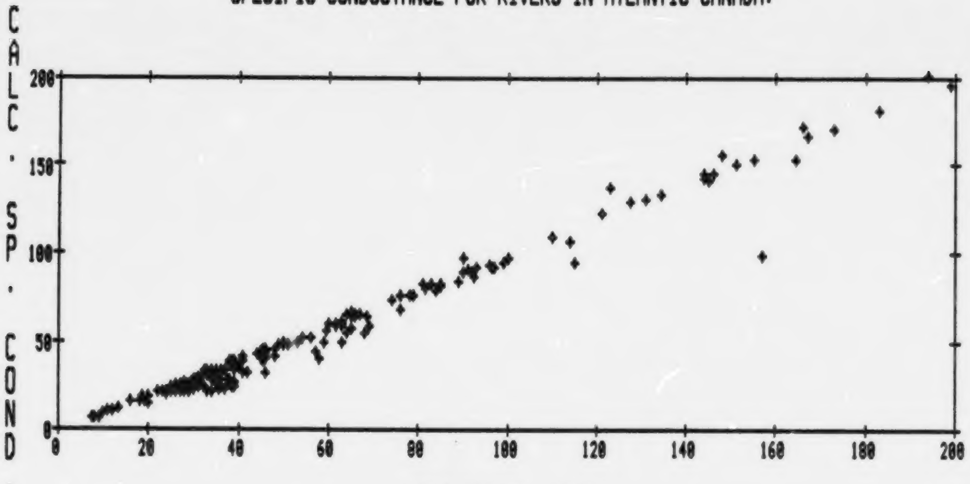
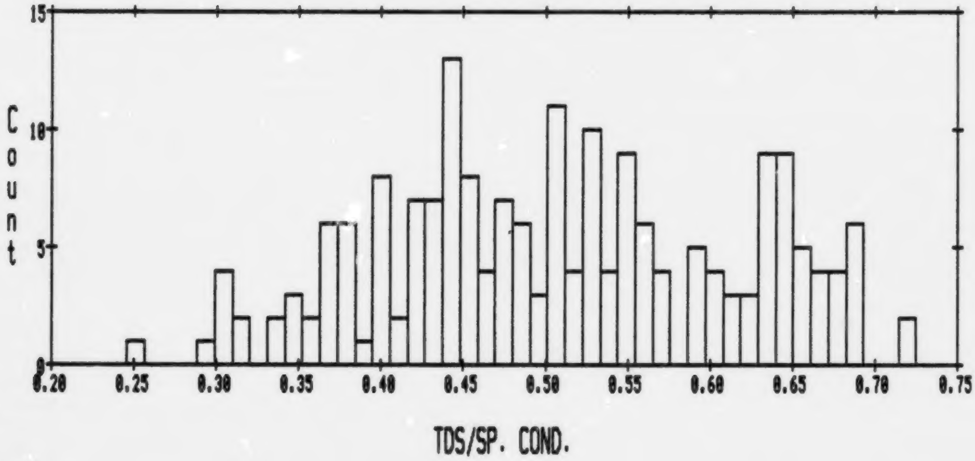


FIGURE 8: THE RATIO OF TOTAL DISSOLVED SALTS TO SPECIFIC CONDUCTANCE FOR RIVERS IN ATLANTIC CANADA.



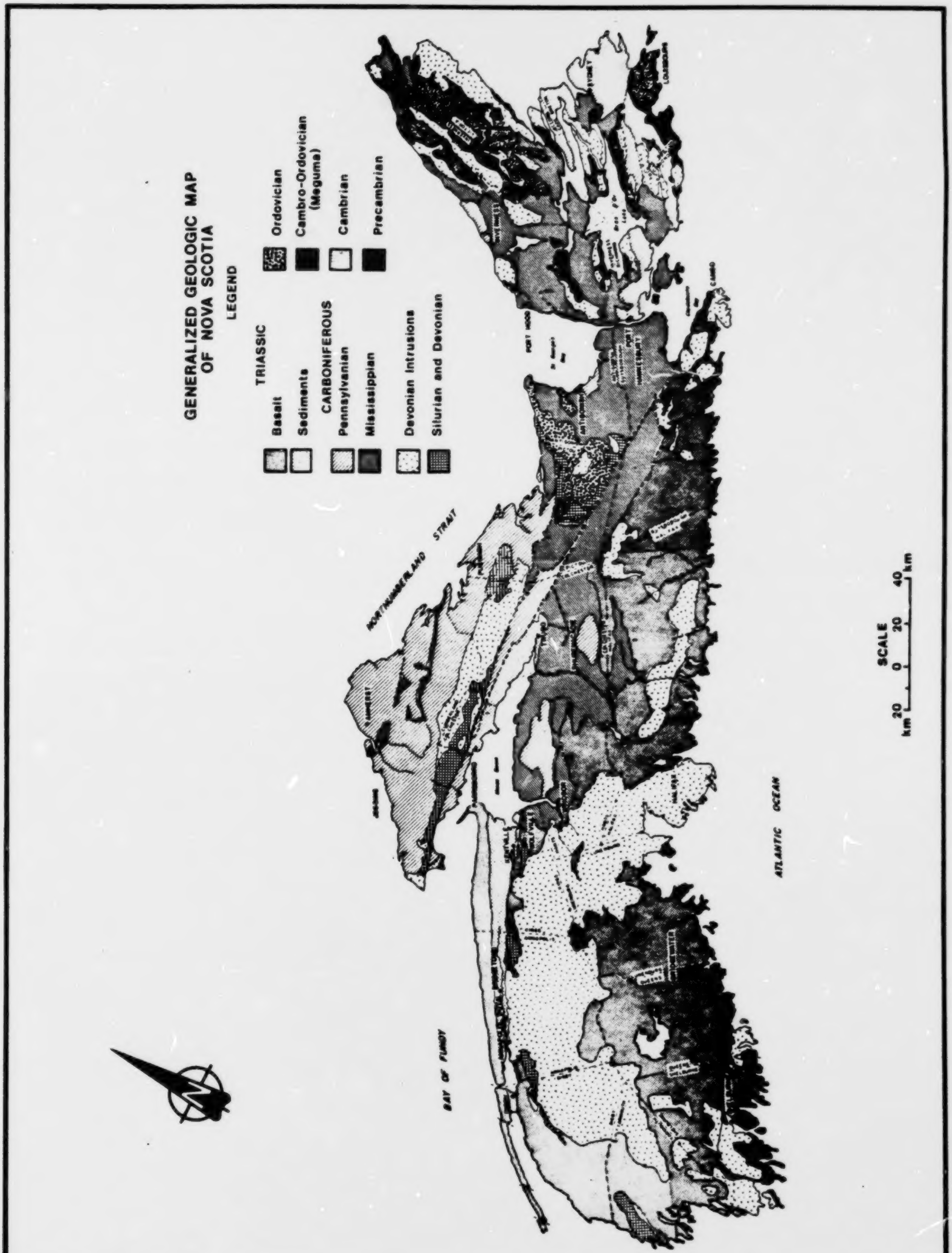

GENERALIZED GEOLOGIC MAP
OF NOVA SCOTIA
LEGEND
TRIASSIC
Basalt
Sediments
CARBONIFEROUS
Pennsylvanian
Mississippian
Devonian Intrusions
Silurian and Devonian
Ordovician
Cambro-Ordovician (Meguma)
Cambrian
Precambrian
NORTHUMBERLAND STRAIT
BAY OF FUNDY
ATLANTIC OCEAN
PORT HOOD
CANSO
LOUISBOURG
SCALE
km 20 0 20 40 km

Figure 9 - A Map of the Generalized Geological Structure of Nova Scotia

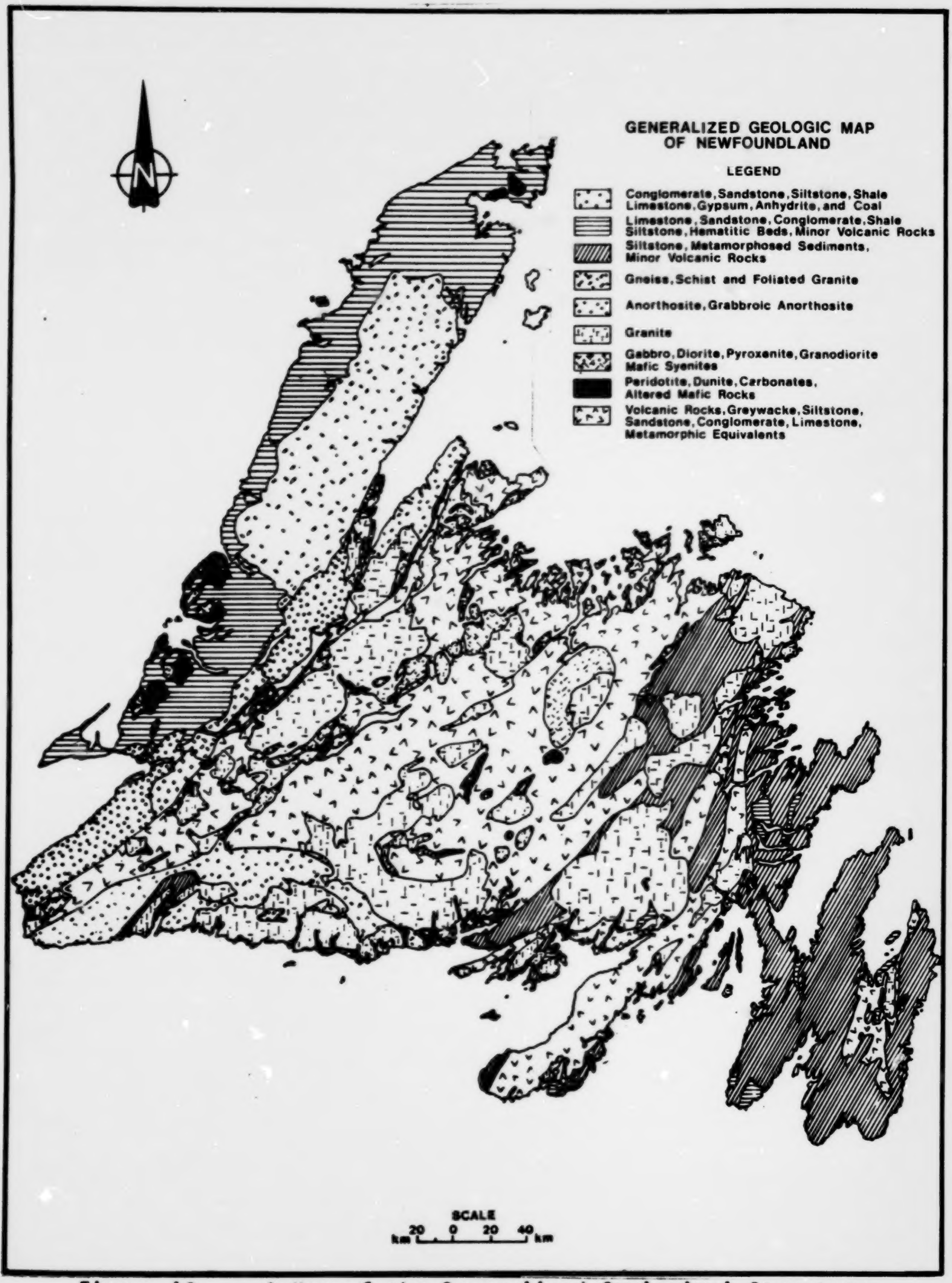

N
GENERALIZED GEOLOGIC MAP
OF NEWFOUNDLAND
LEGEND
Conglomerate, Sandstone, Siltstone, Shale Limestone, Gypsum, Anhydrite, and Coal
Limestone, Sandstone, Conglomerate, Shale Siltstone, Hematitic Beds, Minor Volcanic Rocks
Siltstone, Metamorphosed Sediments, Minor Volcanic Rocks
Gneiss, Schist and Foliated Granite
Anorthosite, Grabbroic Anorthosite
Granite
Gabbro, Diorite, Pyroxenite, Granodiorite Mafic Syenites
Peridotite, Dunite, Carbonates, Altered Mafic Rocks
Volcanic Rocks, Greywacke, Siltstone, Sandstone, Conglomerate, Limestone, Metamorphic Equivalents
SCALE
km 20 0 20 40 km

Figure 10 - A Map of the Generalized Geological Structure of Insular Newfoundland

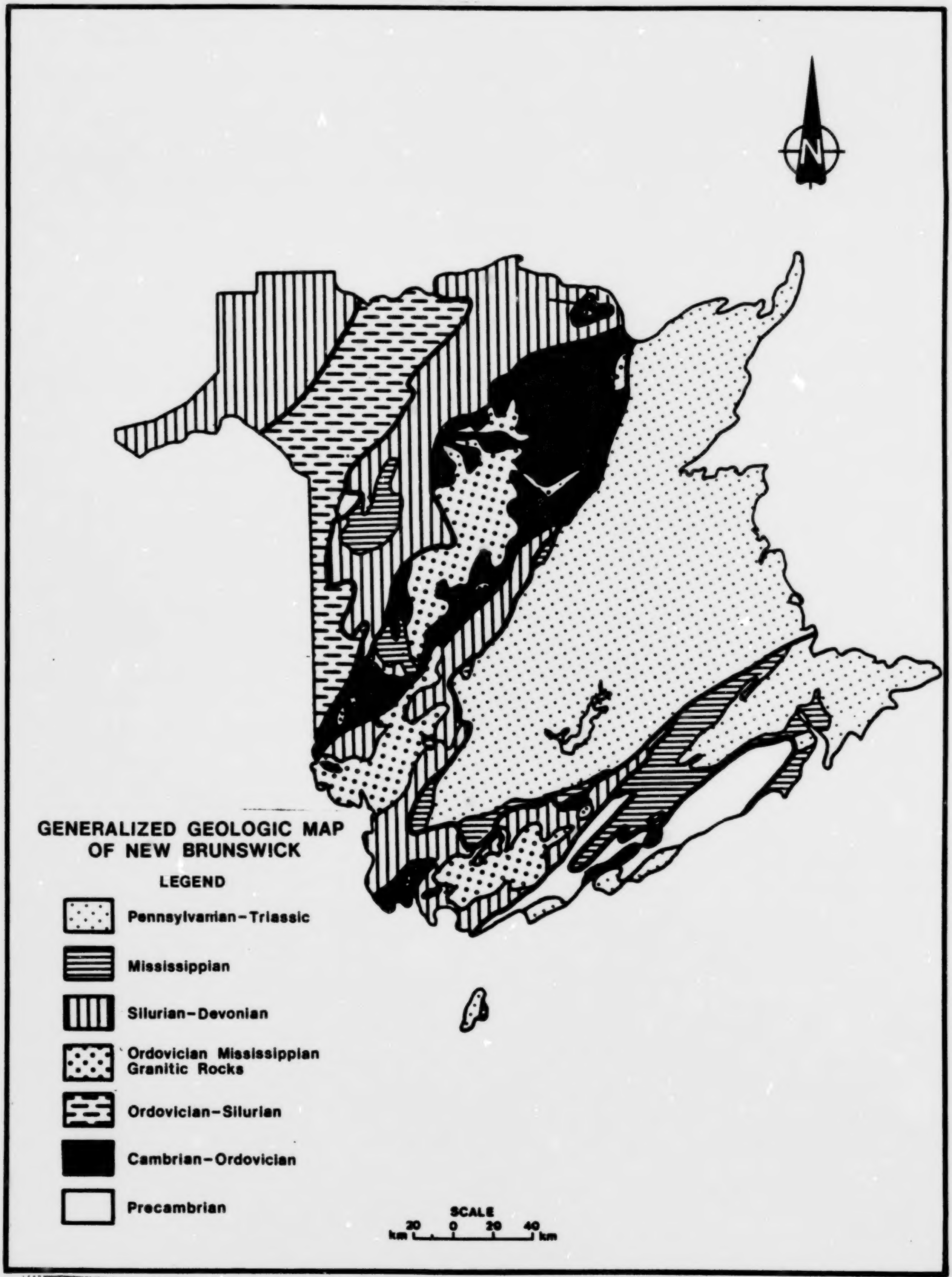

N
GENERALIZED GEOLOGIC MAP
OF NEW BRUNSWICK
LEGEND
Pennsylvanian-Triassic
Mississippian
Silurian-Devonian
Ordovician Mississippian Granitic Rocks
Ordovician-Silurian
Cambrian-Ordovician
Precambrian
SCALE
20 0 20 40
km km

Figure 11 - A Map of the Generalized Geological Structure of New Brunswick

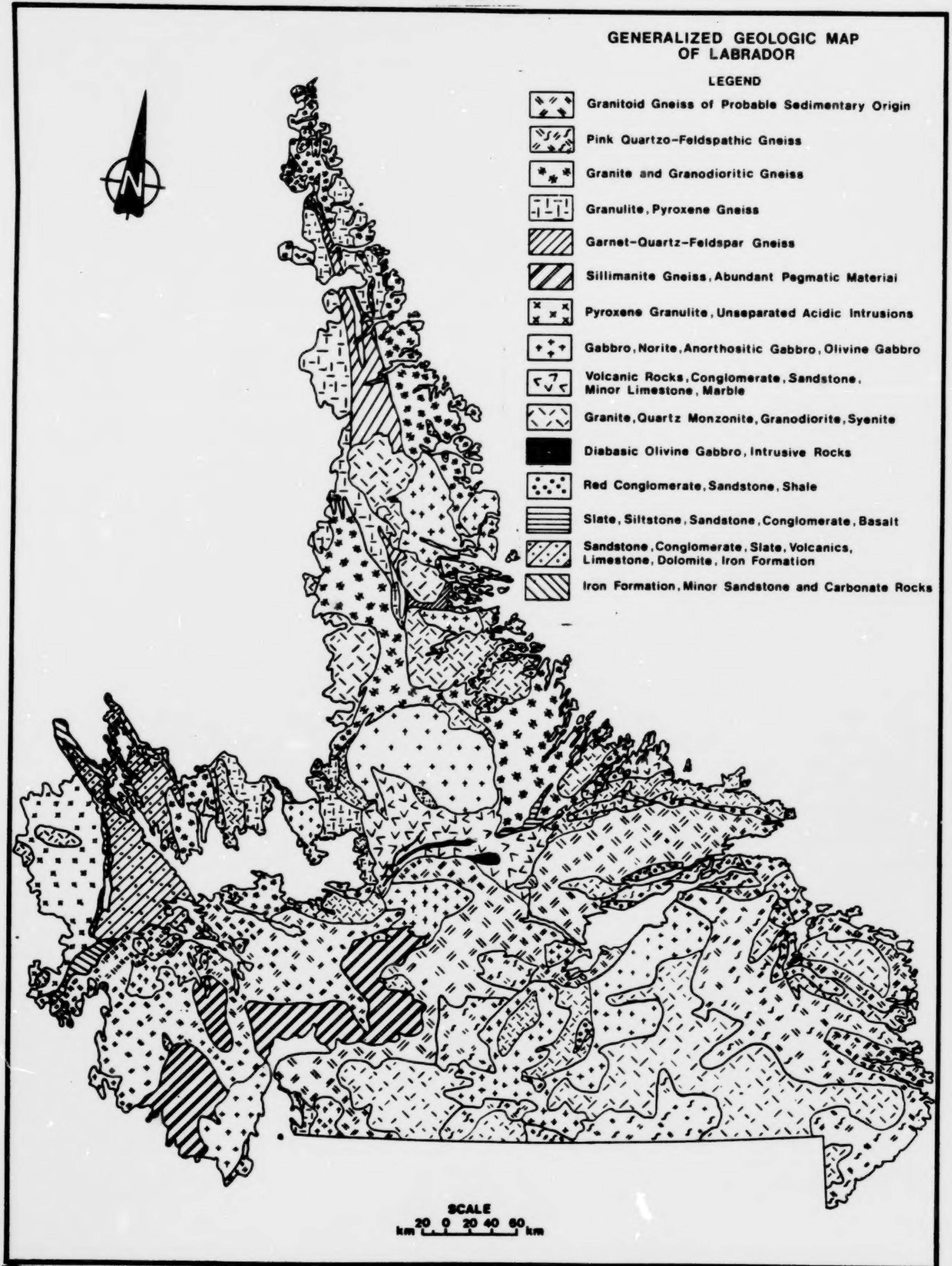

GENERALIZED GEOLOGIC MAP OF LABRADOR
LEGEND
Granitoid Gneiss of Probable Sedimentary Origin
Pink Quartzo-Feldspathic Gneiss
Granite and Granodioritic Gneiss
Granulite, Pyroxene Gneiss
Garnet-Quartz-Feldspar Gneiss
Sillimanite Gneiss, Abundant Pegmatic Material
Pyroxene Granulite, Unseparated Acidic Intrusions
Gabbro, Norite, Anorthositic Gabbro, Olivine Gabbro
Volcanic Rocks, Conglomerate, Sandstone, Minor Limestone, Marble
Granite, Quartz Monzonite, Granodiorite, Syenite
Diabasic Olivine Gabbro, Intrusive Rocks
Red Conglomerate, Sandstone, Shale
Slate, Siltstone, Sandstone, Conglomerate, Basalt
Sandstone, Conglomerate, Slate, Volcanics, Limestone, Dolomite, Iron Formation
Iron Formation, Minor Sandstone and Carbonate Rocks
N
SCALE
km 20 0 20 40 60 km

Figure 12 - A Map of the Generalized Geological Structure of Labrador

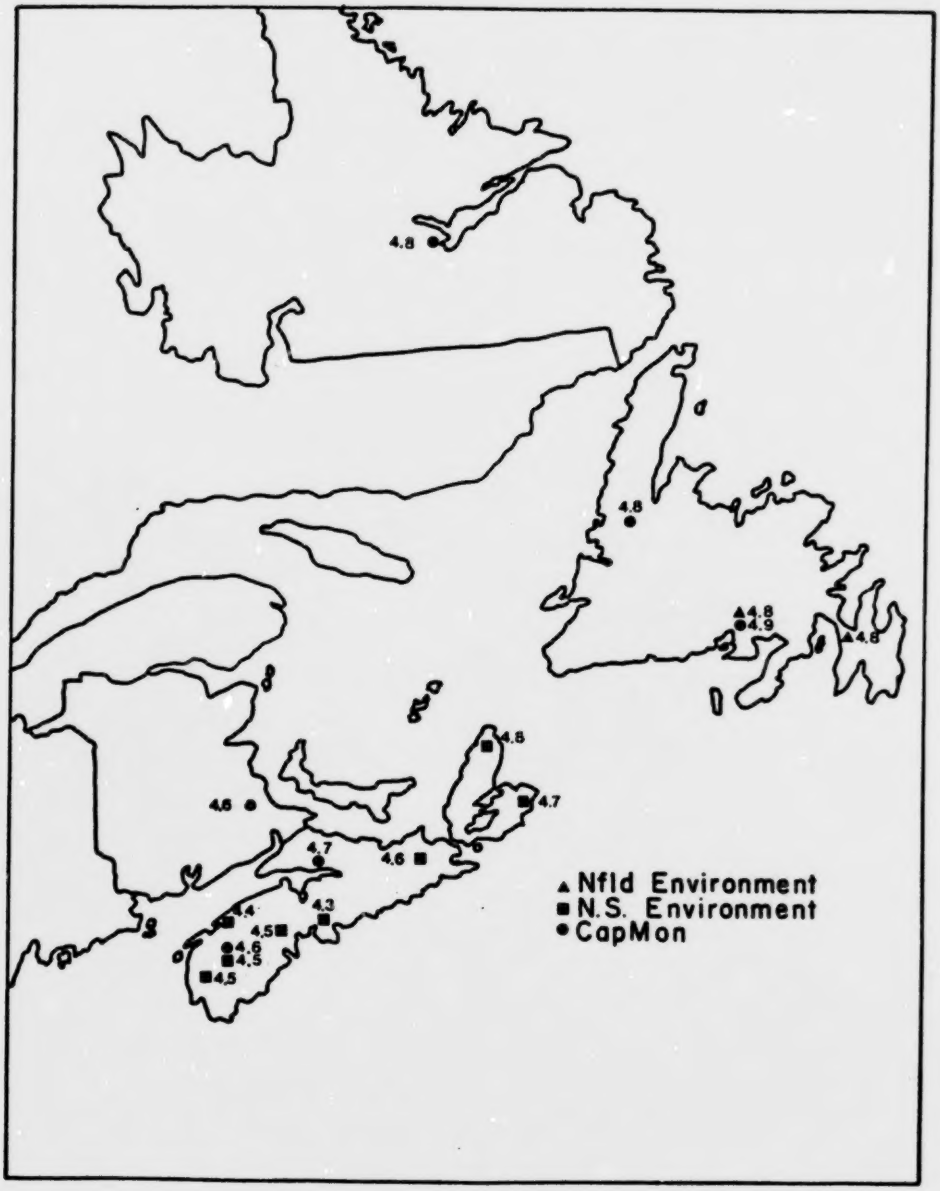

4.8
4.8
4.8
4.9
4.8
4.8
4.7
4.6
4.7
4.6
4.4
4.3
4.5
4.6
4.5
4.5
▲ Nfld Environment
■ N.S. Environment
● CapMon

FIGURE 13: ANNUAL MEAN PRECIPITATION pH VALUES FOR SELECTED ATLANTIC CANADA MONITORING SITES.

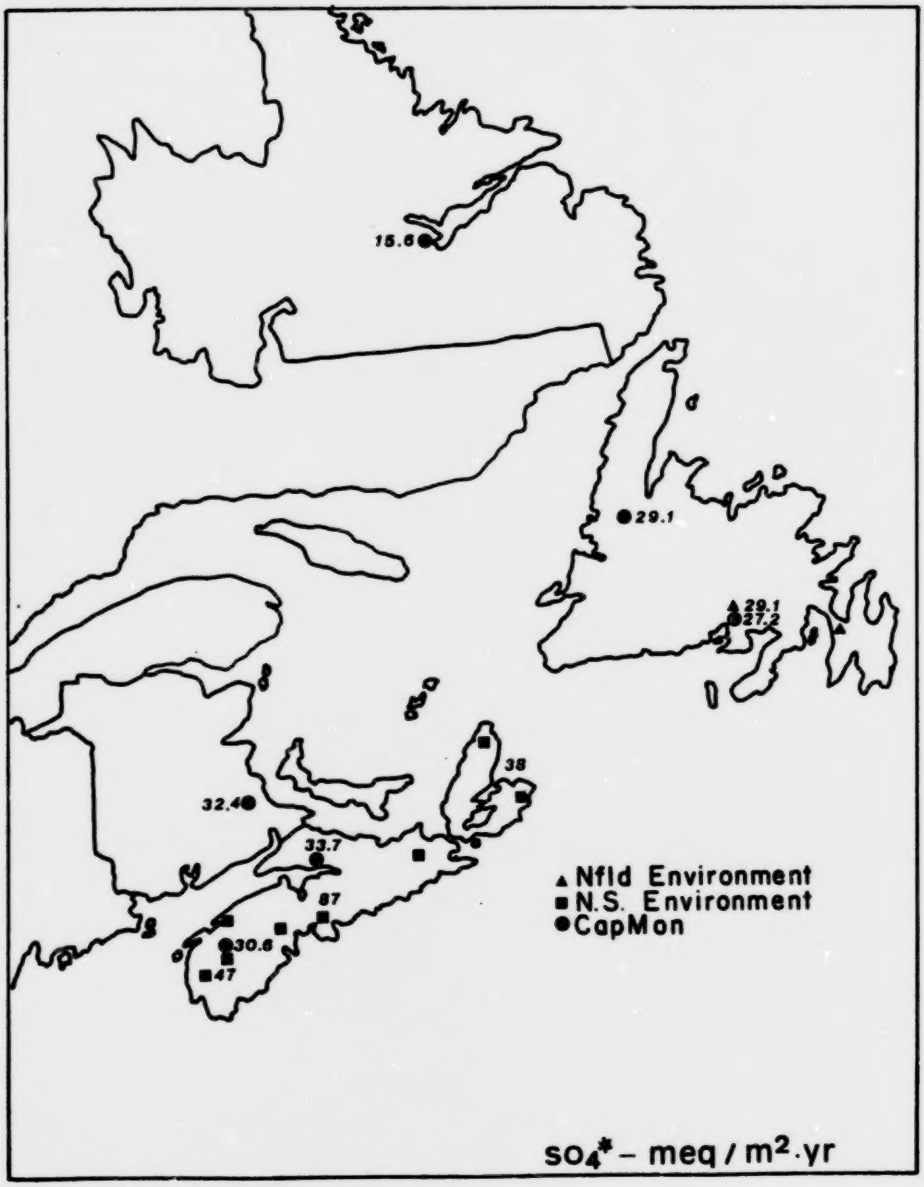

15.6
29.1
29.1
27.2
32.4
33.7
38
87
30.6
47
▲Nfld Environment
■N.S. Environment
●CapMon
SO4* – meq / m2·yr

FIGURE 14: ANNUAL EXCESS WET SULPHATE DEPOSITION VALUES FOR SELECTED ATLANTIC CANADA MONITORING SITES.

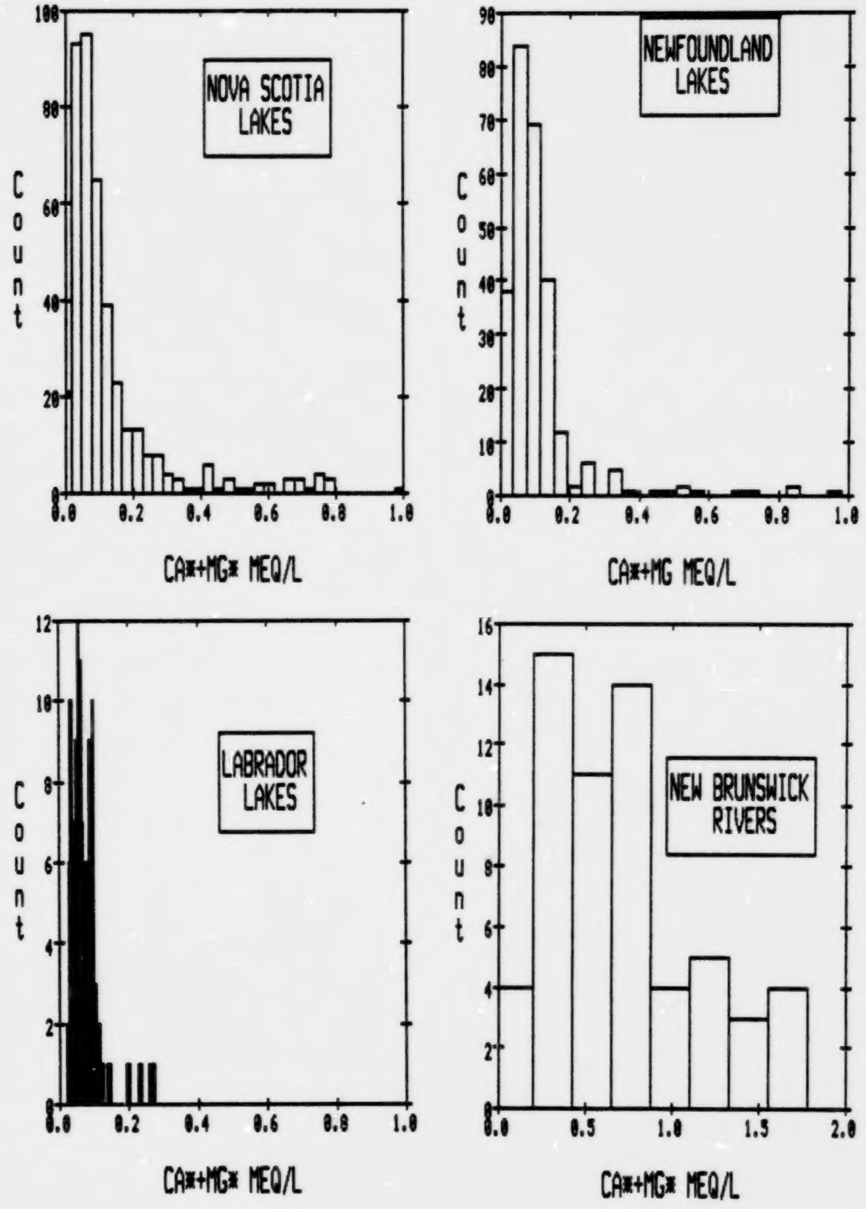


FIGURE 15: HISTOGRAMS OF THE SUM OF EXCESS CALCIUM AND MAGNESIUM CONCENTRATIONS FOR LAKES AND RIVERS IN THE ATLANTIC PROVINCES.

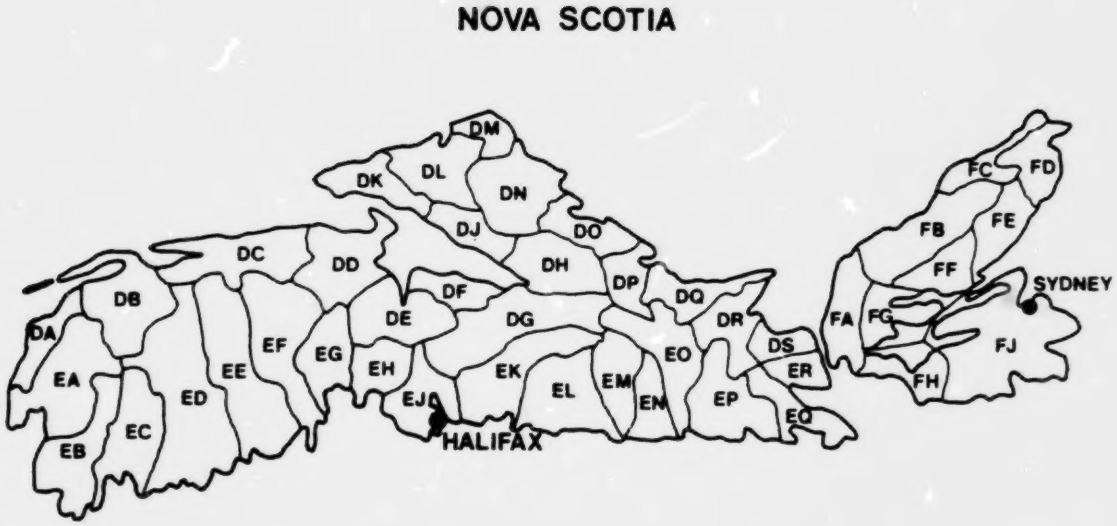
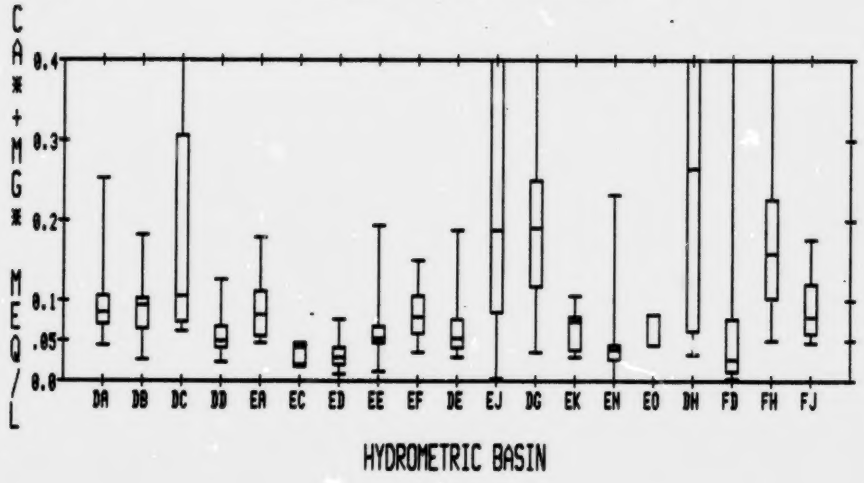
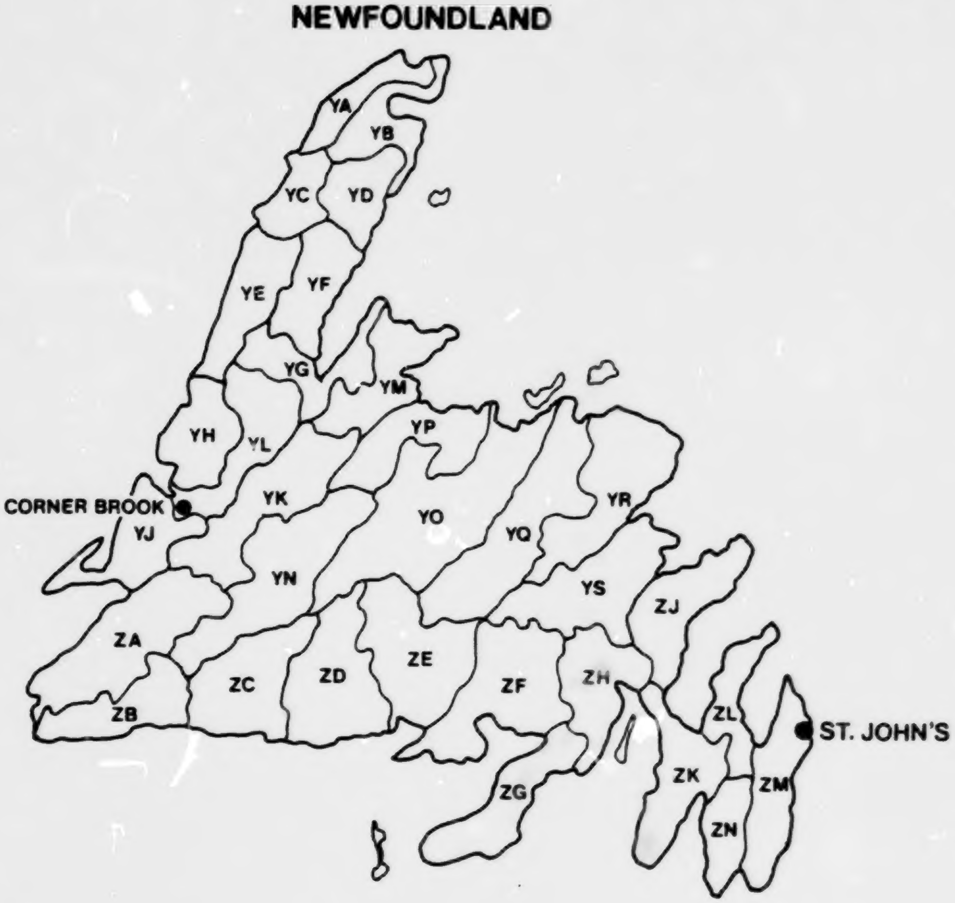

NOVA SCOTIA
DM
DK
DL
DN
DJ
DO
DC
DD
DH
DB
DF
DP
DQ
DA
DE
DG
DR
EF
EG
EO
DS
EA
EE
EH
EK
EM
ER
ED
EJ
EL
EN
EP
EQ
EC
EB
HALIFAX
FC
FD
FE
FB
FF
SYDNEY
FA
FG
FJ
FH

FIGURE 16: BOXPLOT OF THE SUM OF EXCESS CALCIUM AND EXCESS MAGNESIUM CONCENTRATION FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.




NEWFOUNDLAND
YA
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CORNER BROOK
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YJ
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YS
ZJ
ZA
ZE
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ZL
ST. JOHN'S
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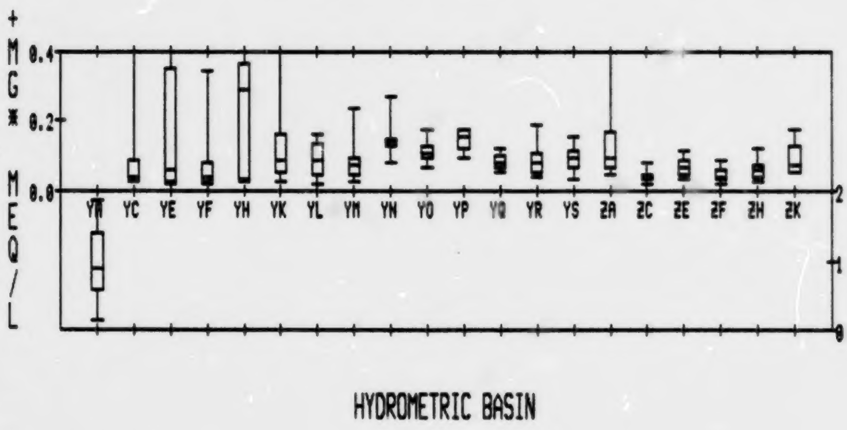
FIGURE 17: BOXPLOT OF EXCESS CALCIUM AND MAGNESIUM FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.



LABRADOR

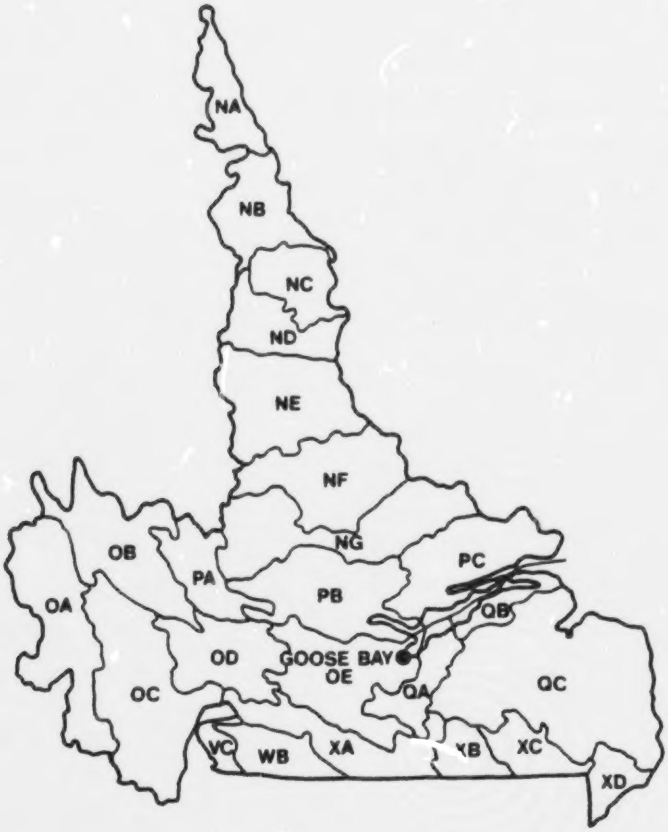

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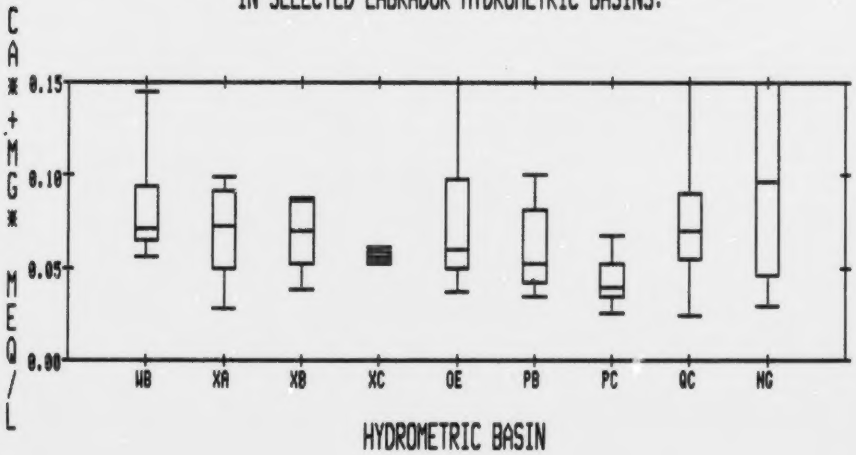
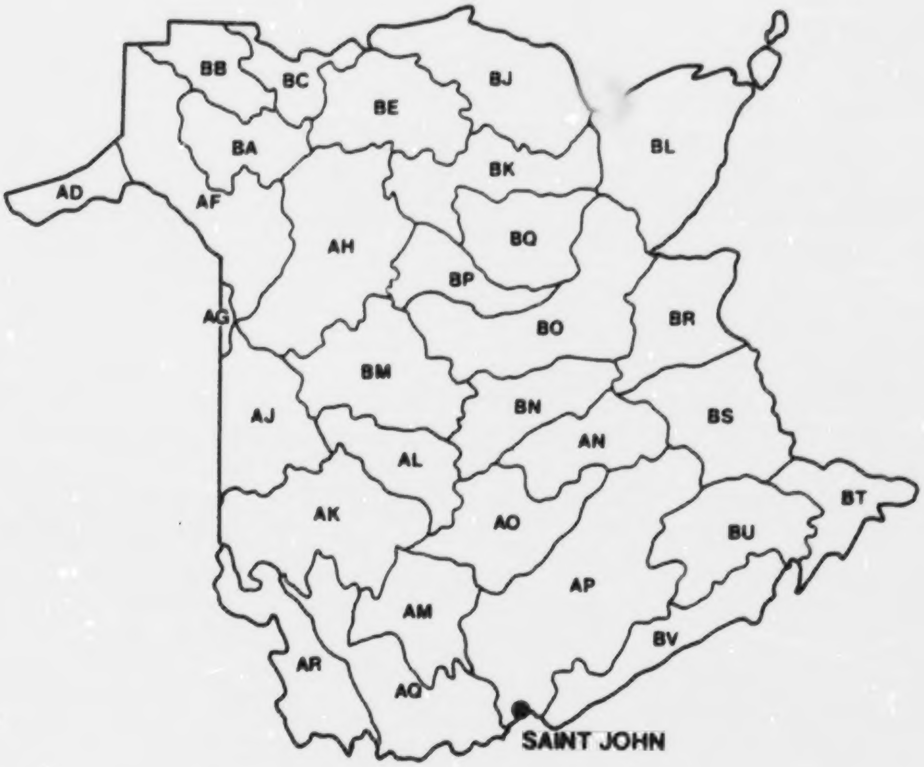
FIGURE 18: BOXPLOT OF EXCESS CALCIUM AND MAGNESIUM FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS.



NEW BRUNSWICK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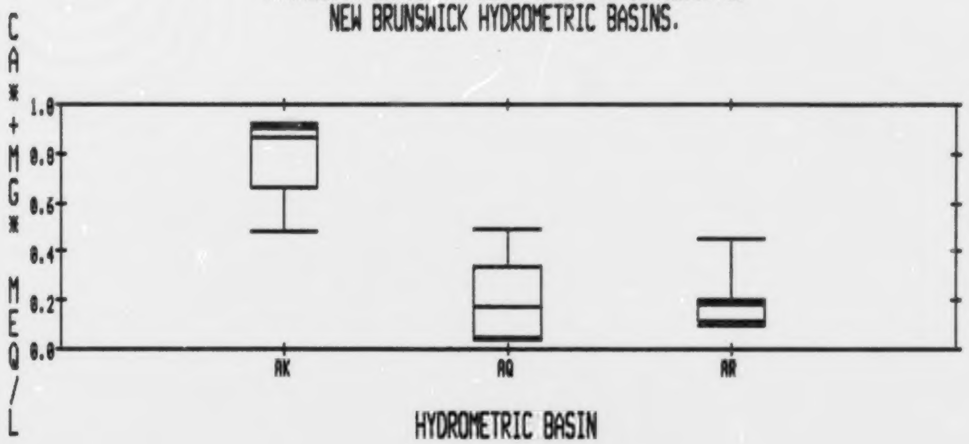
SAINT JOHN

FIGURE 19: BOXPLOT OF THE SUM OF EXCESS CALCIUM AND EXCESS MAGNESIUM CONCENTRATION FOR LAKES IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.



NEW BRUNSWICK

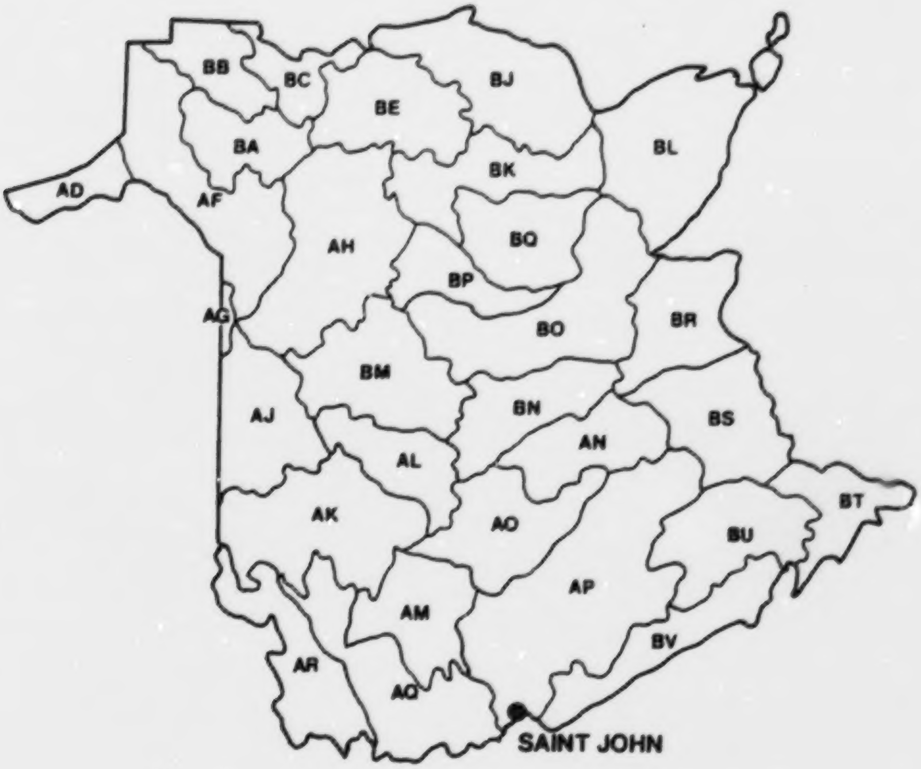

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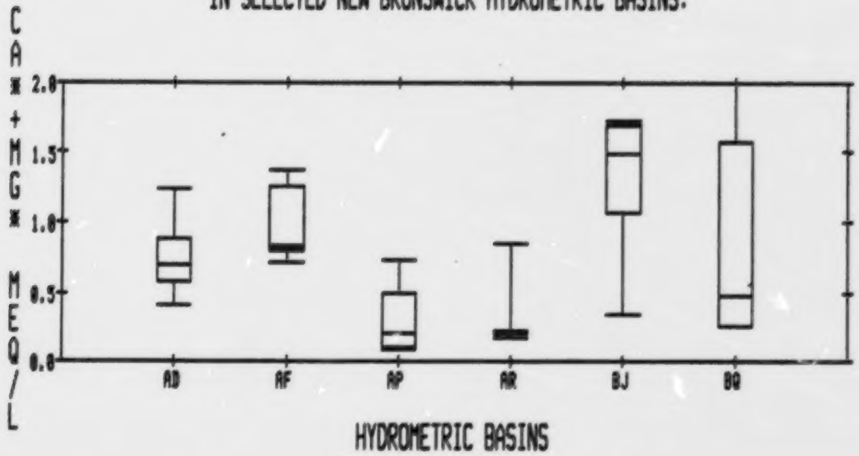
FIGURE :BOXPLOT OF EXCESS CALCIUM AND MAGNESIUM FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.



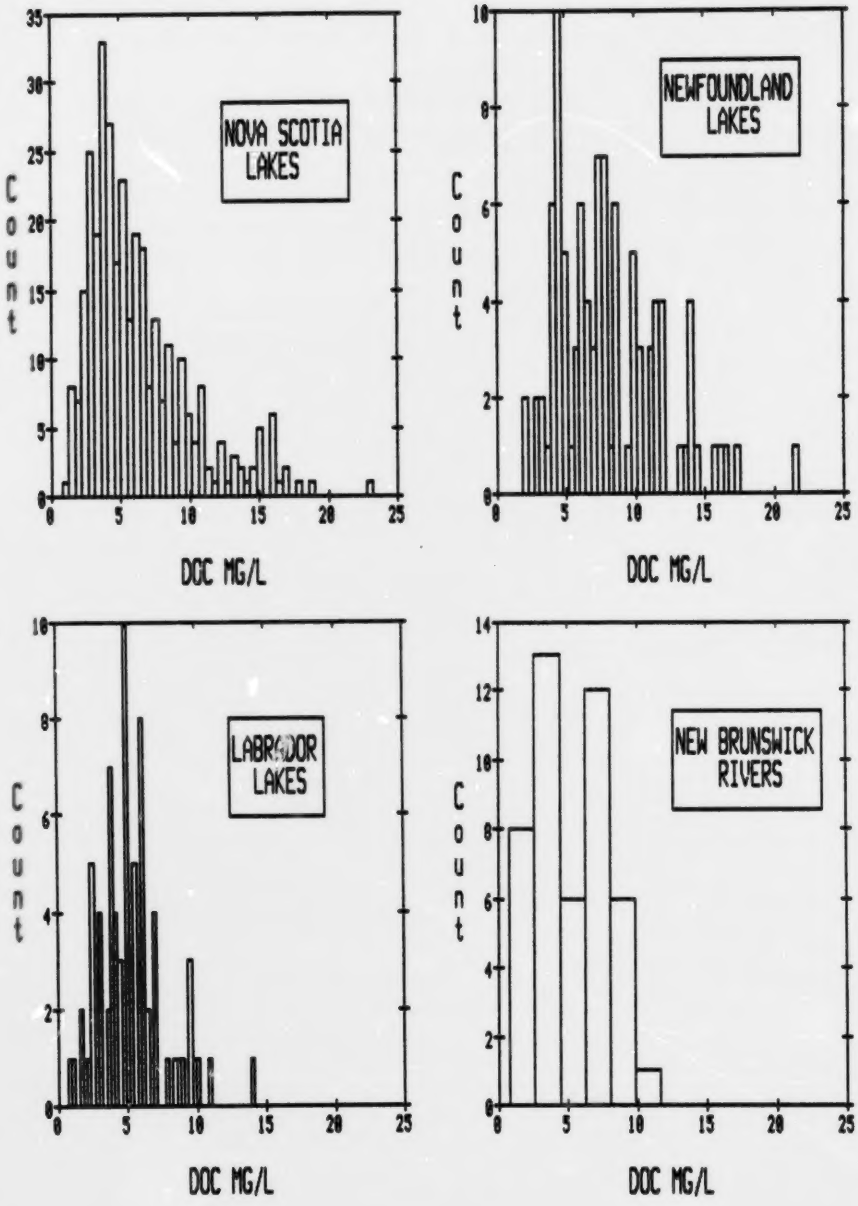


FIGURE 21: HISTOGRAMS OF DISSOLVED ORGANIC CARBON CONCENTRATIONS FOR LAKES AND RIVERS IN THE ATLANTIC PROVINCES.

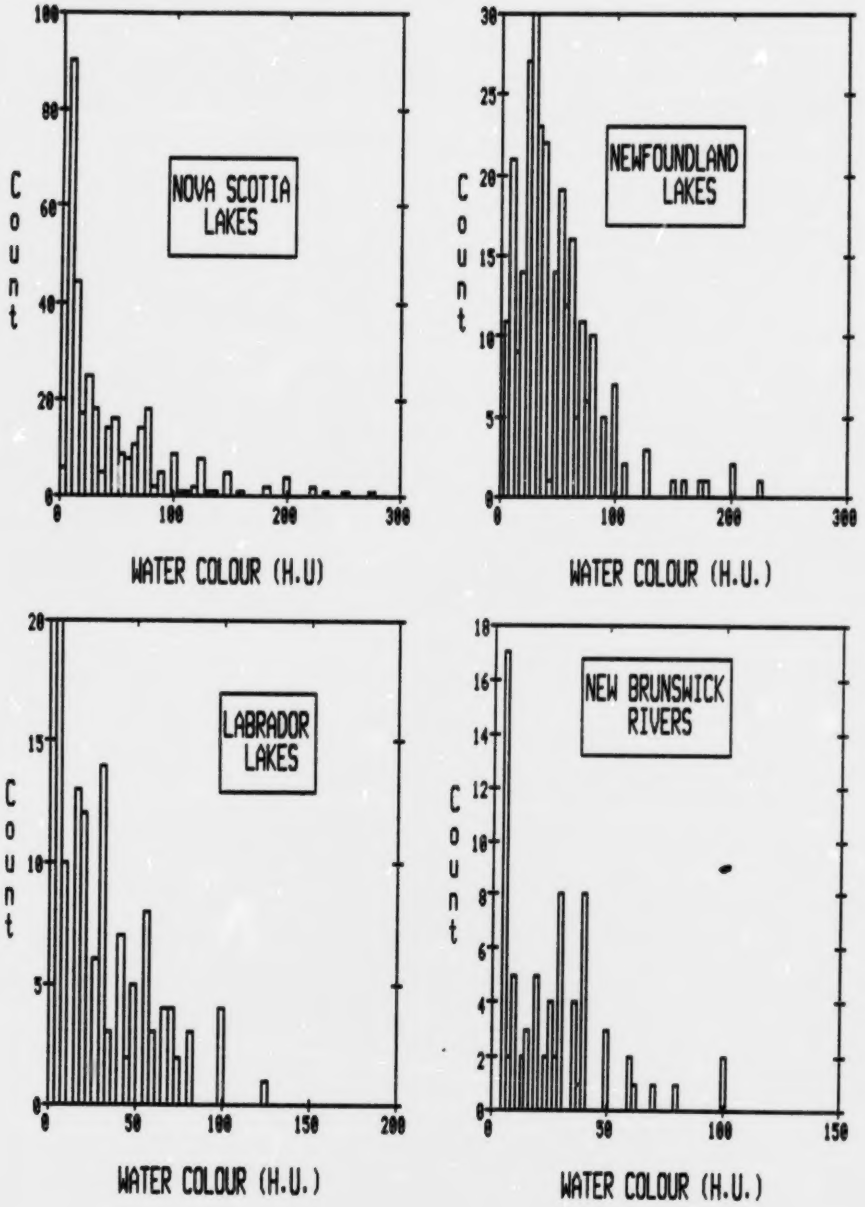


FIGURE 22: HISTOGRAMS OF WATER COLOUR FOR LAKES AND RIVERS IN THE ATLANTIC PROVINCES.

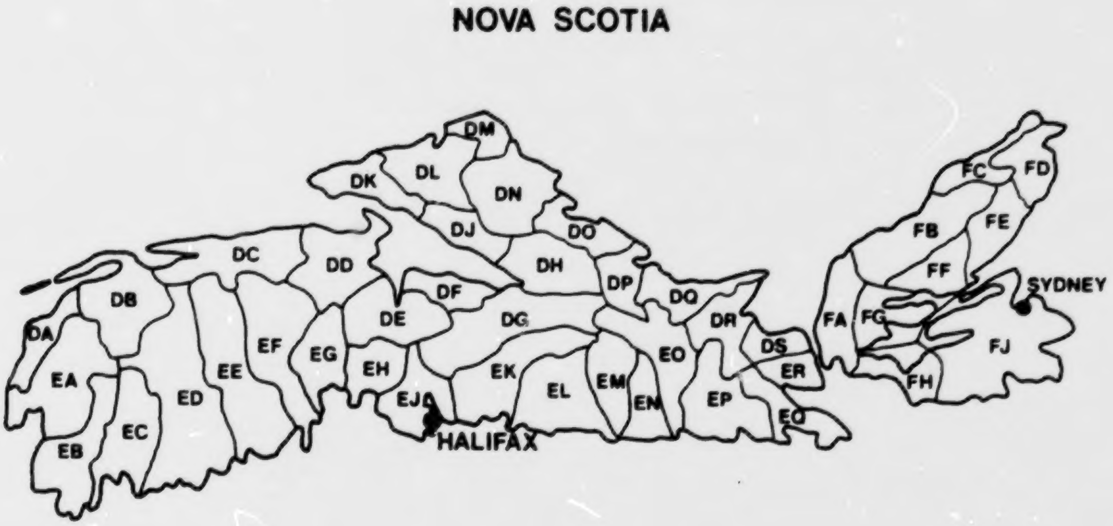

NOVA SCOTIA
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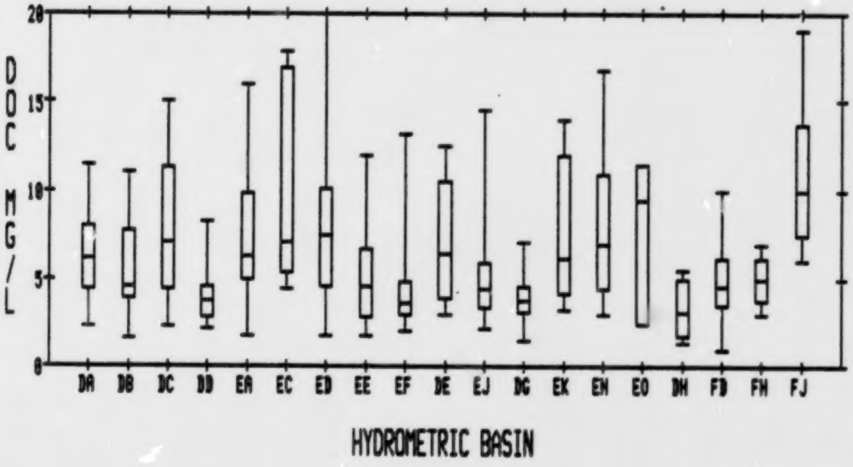
FIGURE 23: BOXPLOT OF DISSOLVED ORGANIC CARBON CONCENTRATION FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.



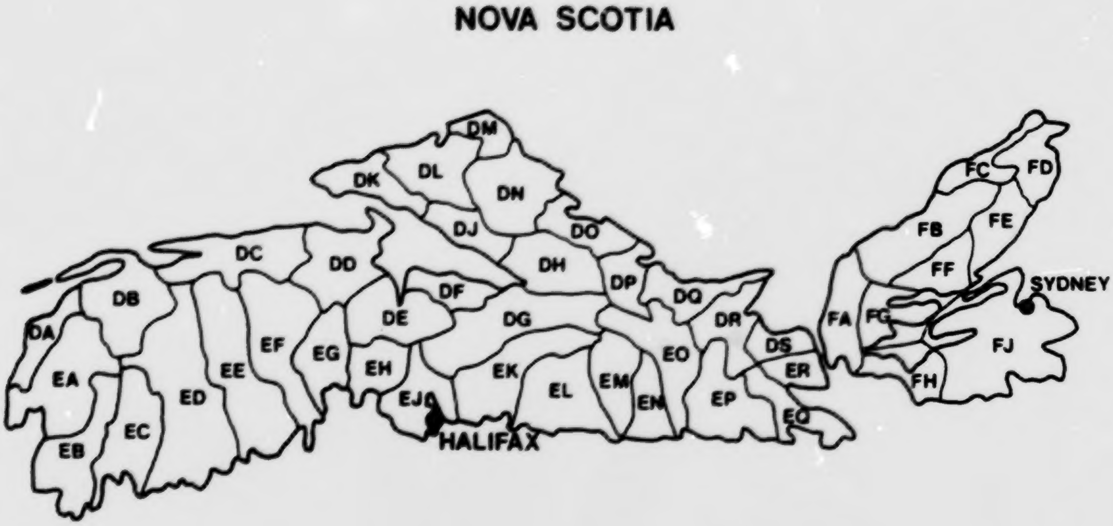

NOVA SCOTIA
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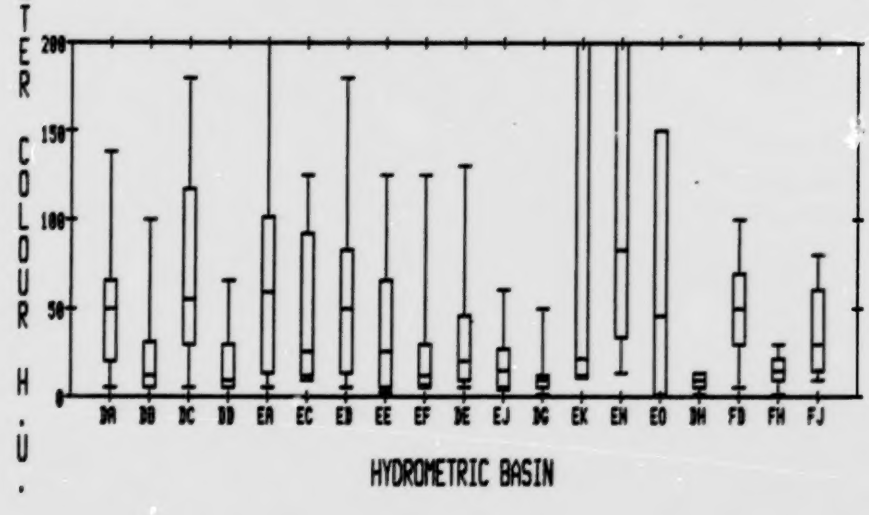
FIGURE 24:BOXPLOT OF WATER COLOUR (HAZEN UNITS) FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.



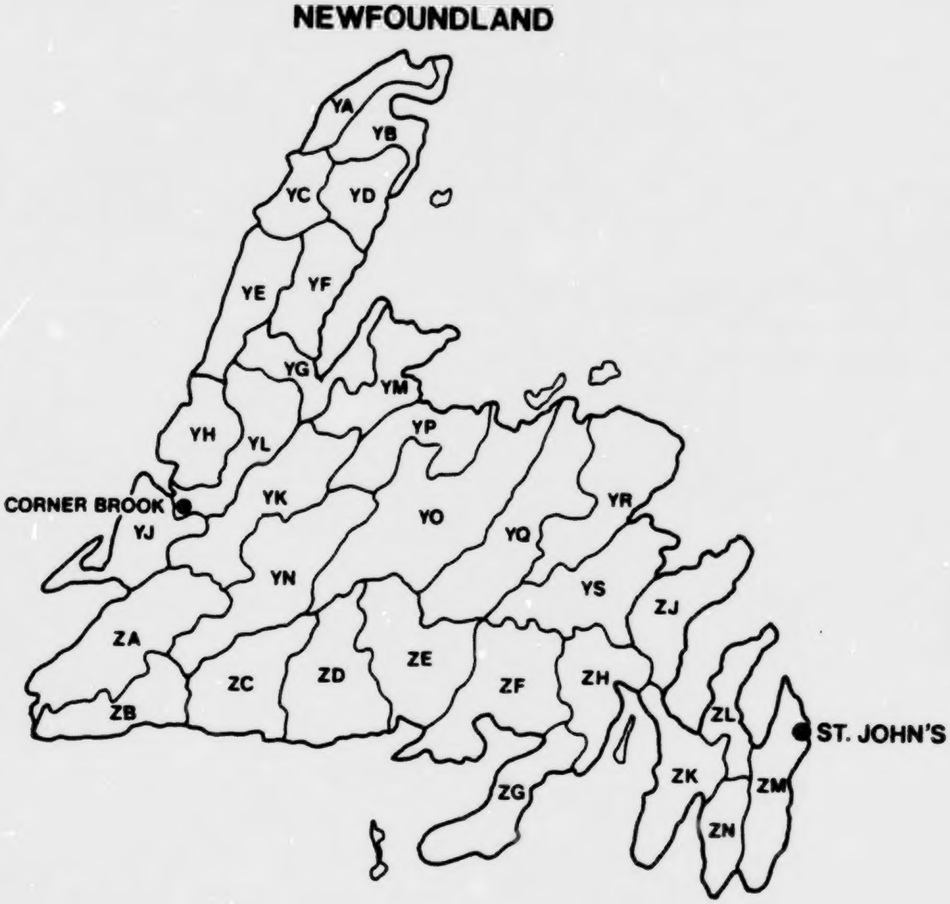

NEWFOUNDLAND
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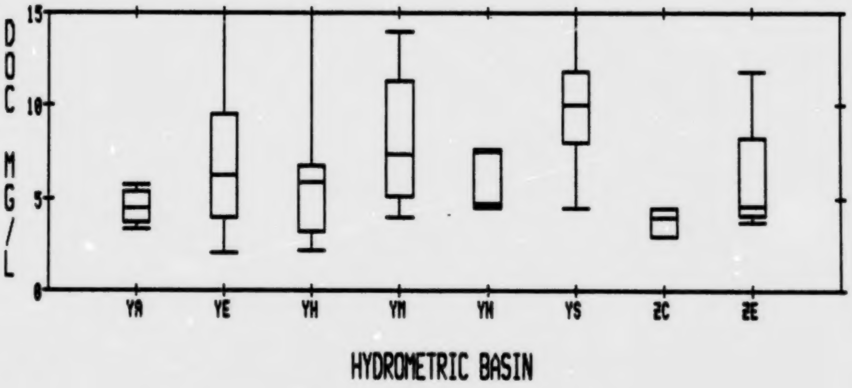
FIGURE 25 :BOXPLOT OF DISSOLVED ORGANIC CONCENTRATION FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.



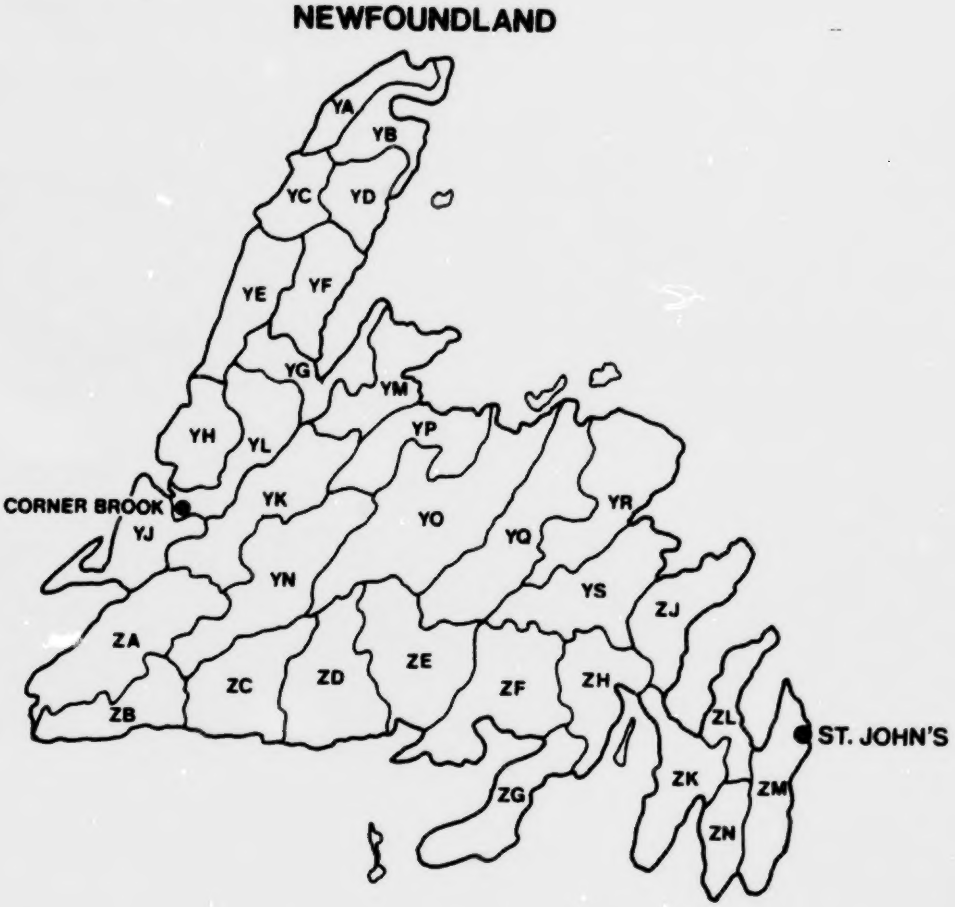

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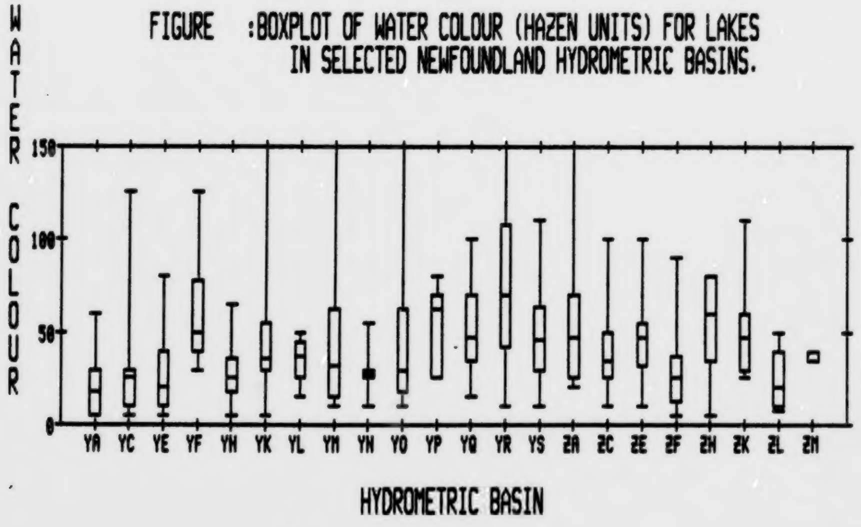
FIGURE :BOXPLOT OF WATER COLOUR (HAZEN UNITS) FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.



LABRADOR

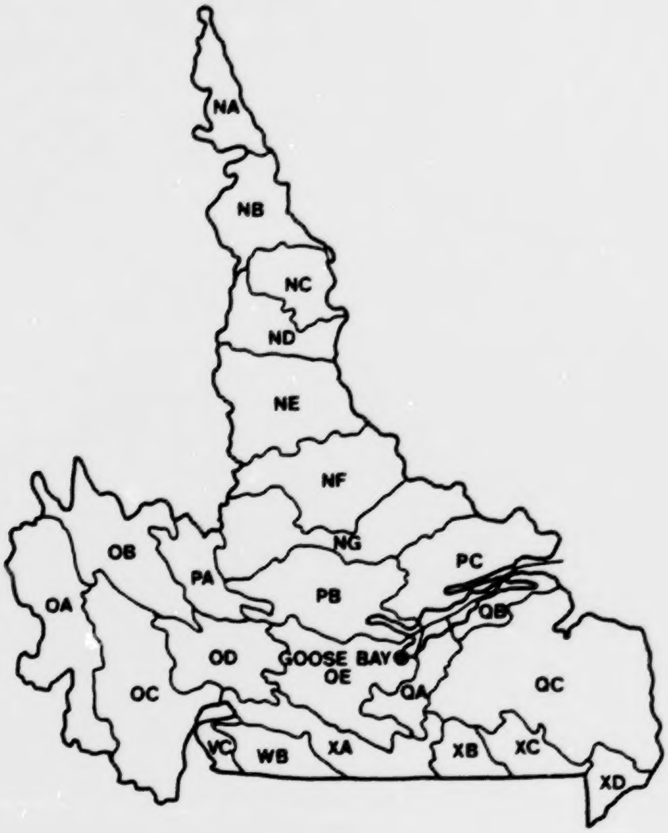

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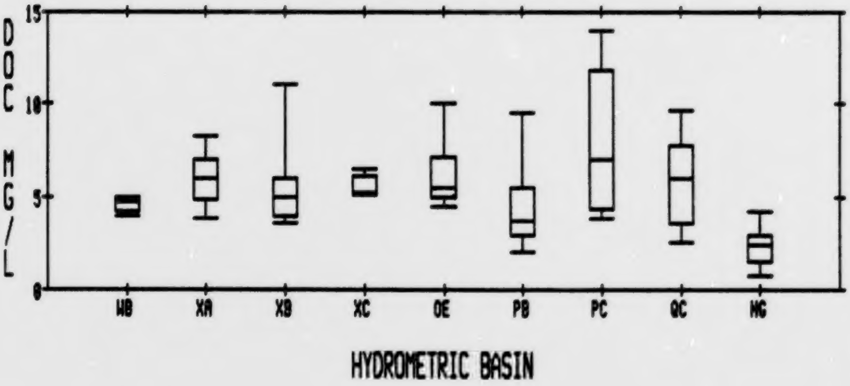
FIGURE :BOXPLOT OF DISSOLVED ORGANIC CARBON CONCENTRATION FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS



LABRADOR

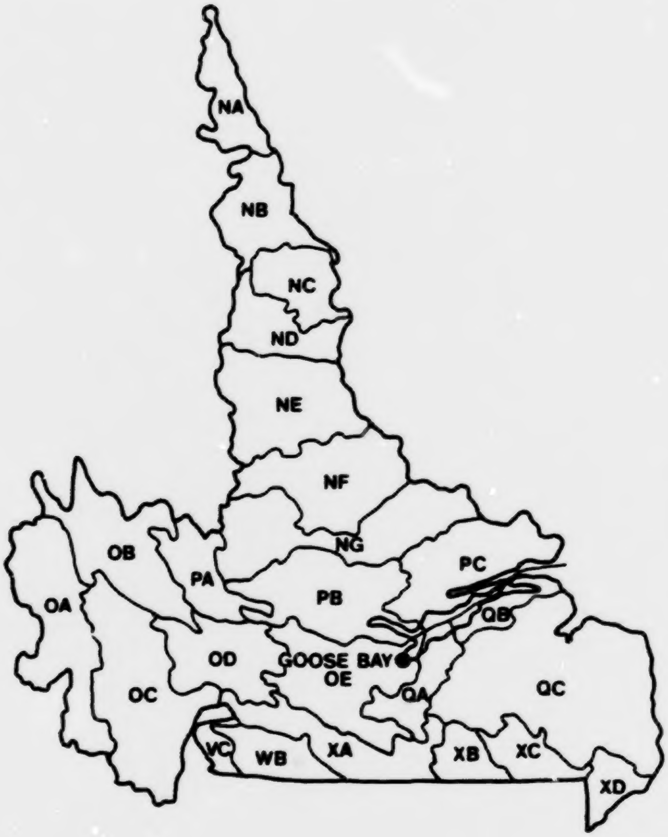

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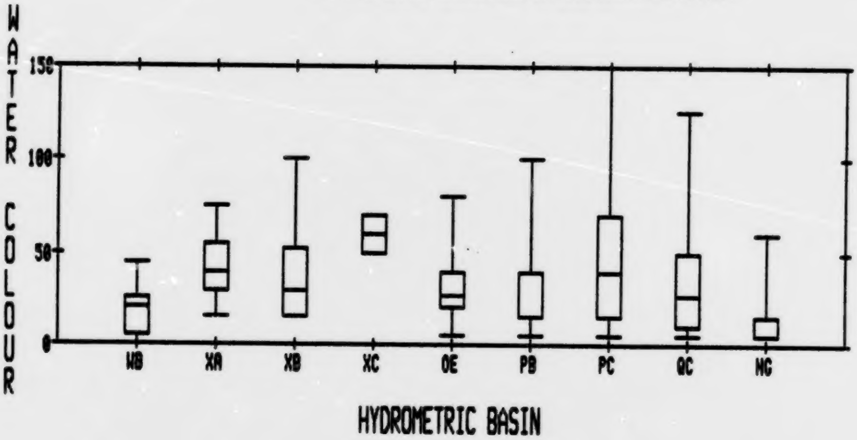
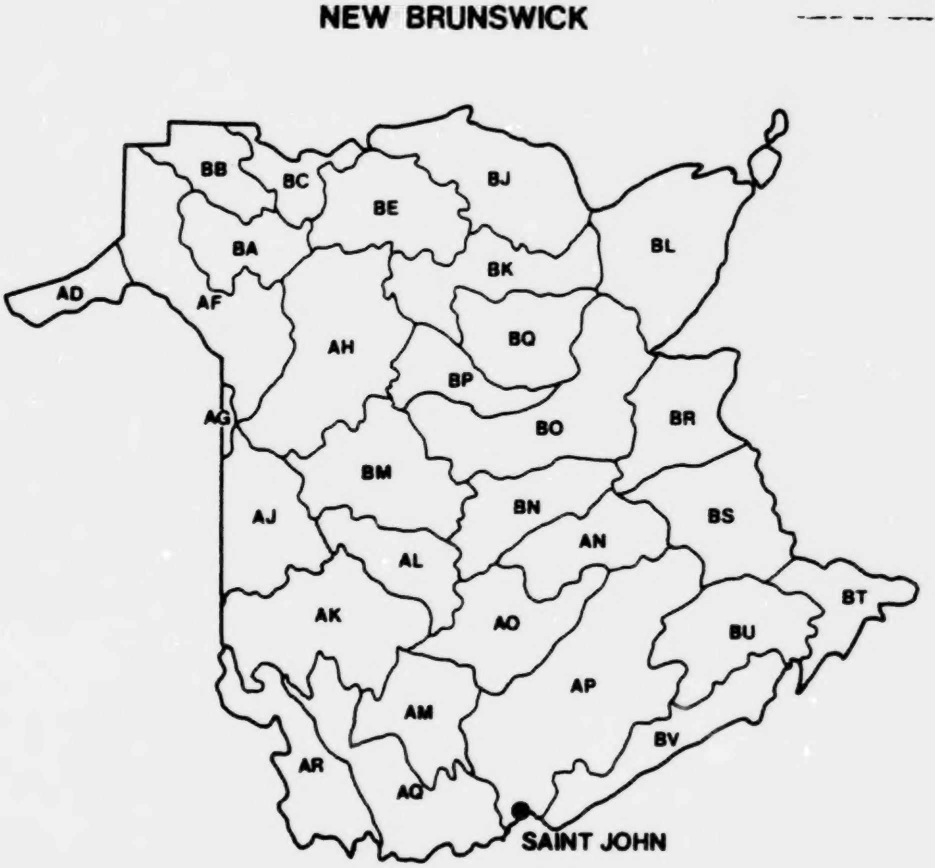
FIGURE 28: BOXPLOT OF WATER COLOUR (HAZEN UNITS) FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS.




NEW BRUNSWICK
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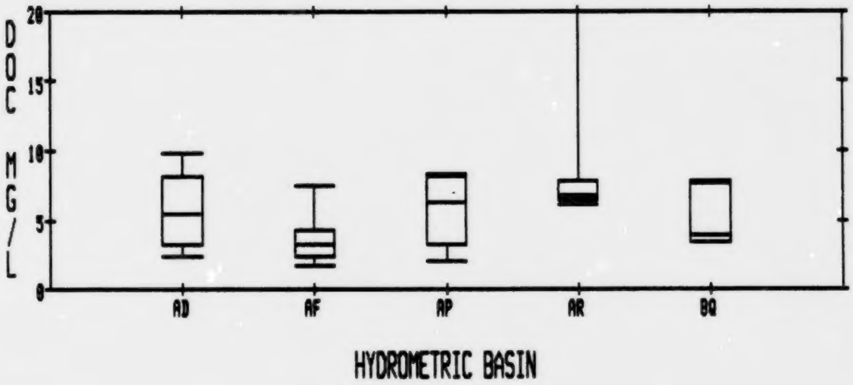
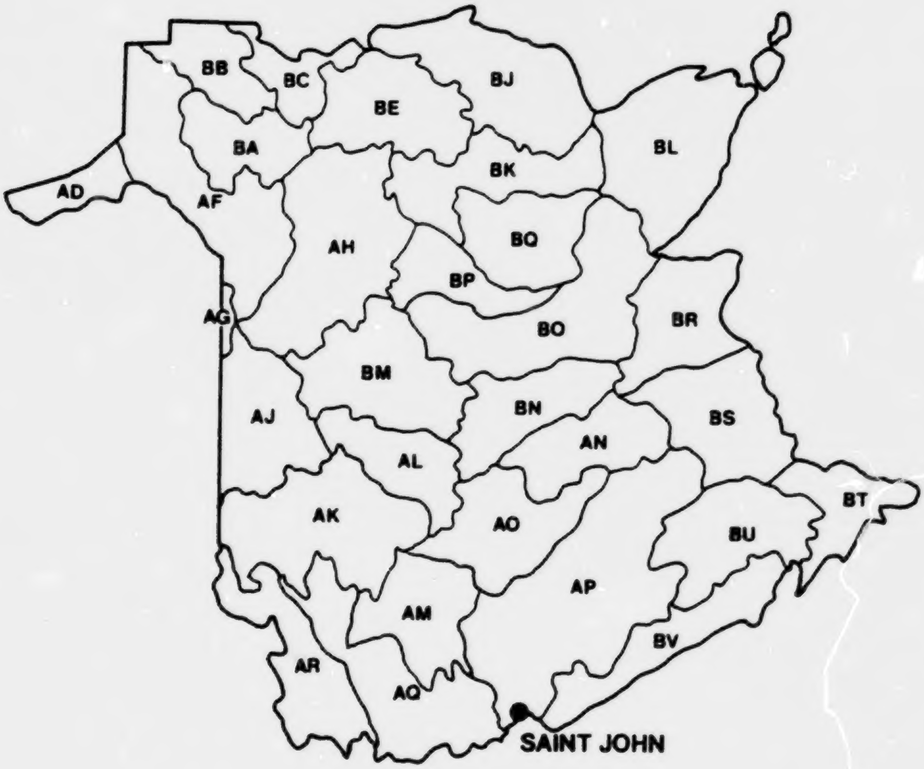
SAINT JOHN

FIGURE 29 : BOXPLOT OF DISSOLVED ORGANIC CARBON CONCENTRATION FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.

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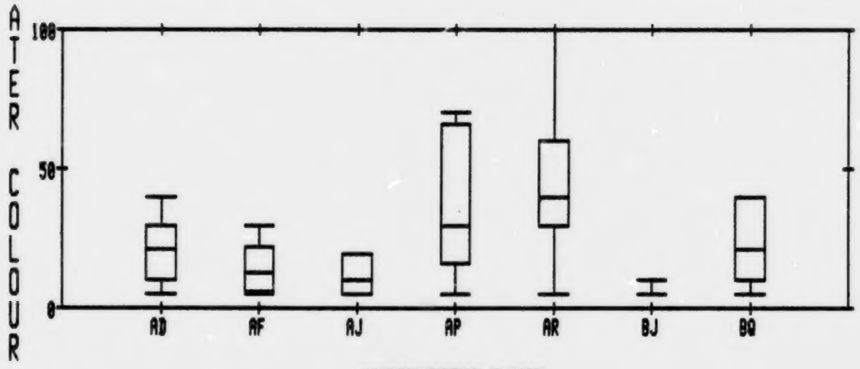
SAINT JOHN

FIGURE 30 : BOXPLOT OF WATER COLOUR (HAZEN UNITS) FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.



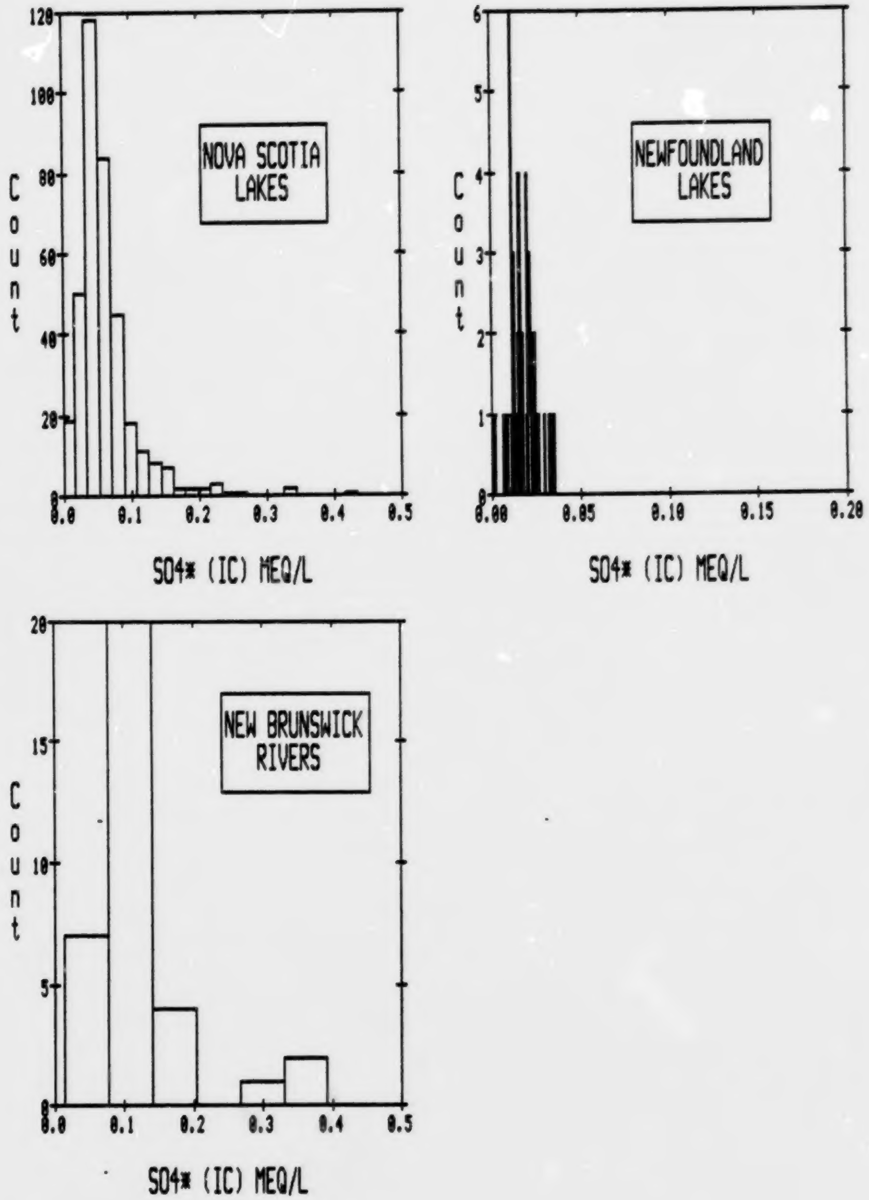


FIGURE 31: HISTOGRAMS OF EXCESS ION CHROMATOGRAPH SULPHATE CONCENTRATIONS FOR LAKES AND RIVERS IN THE ATLANTIC PROVINCES.

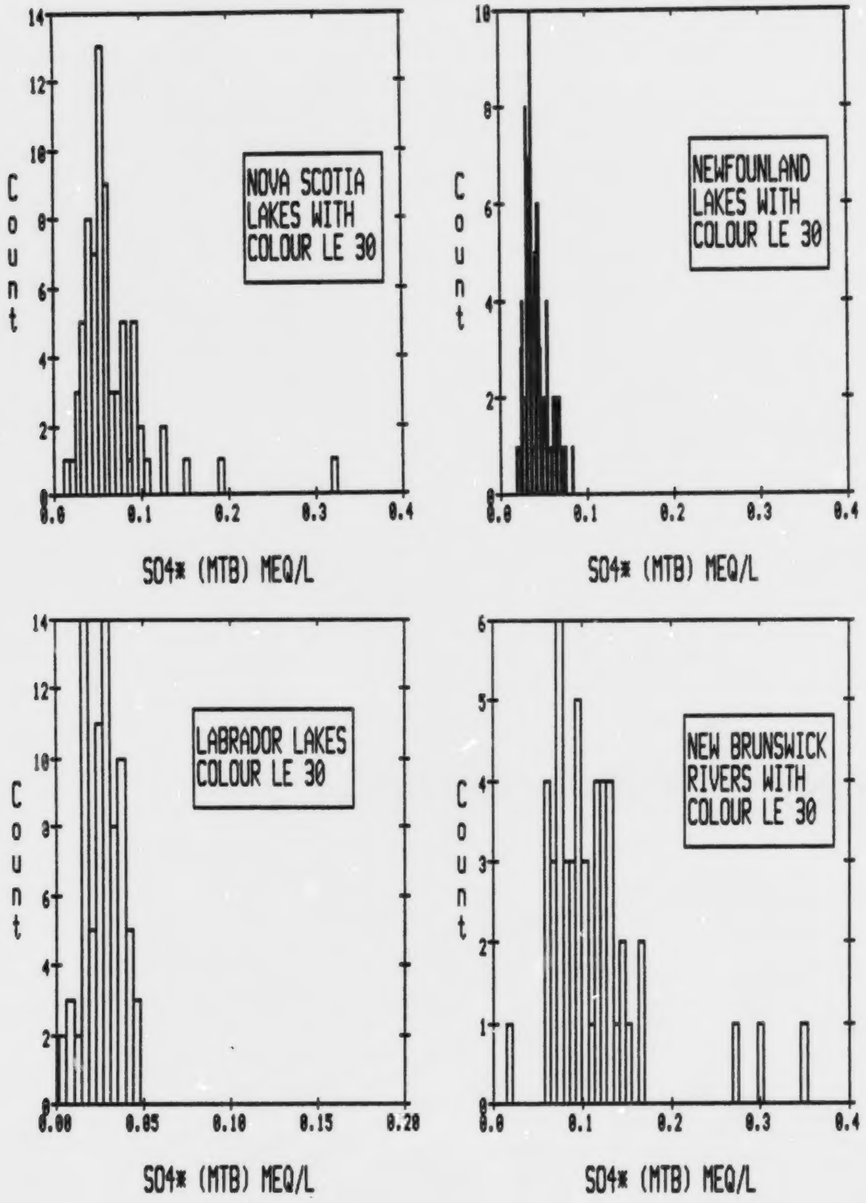


FIGURE 32 :HISTOGRAMS OF EXCESS MTB SULPHATE CONCENTRATIONS FOR LAKES AND RIVERS IN THE ATLANTIC PROVINCES WHICH HAVE WATER COLOURS LESS THAN OR EQUAL TO 30.

NOVA SCOTIA

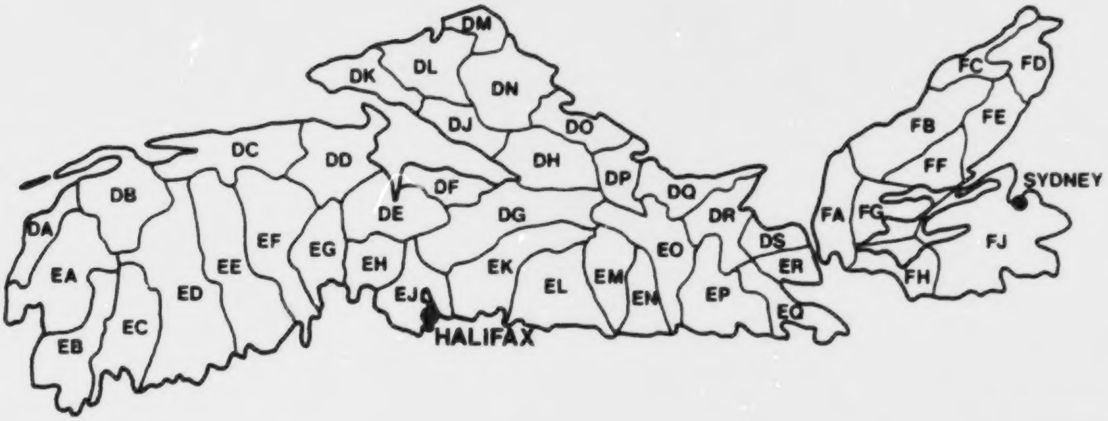

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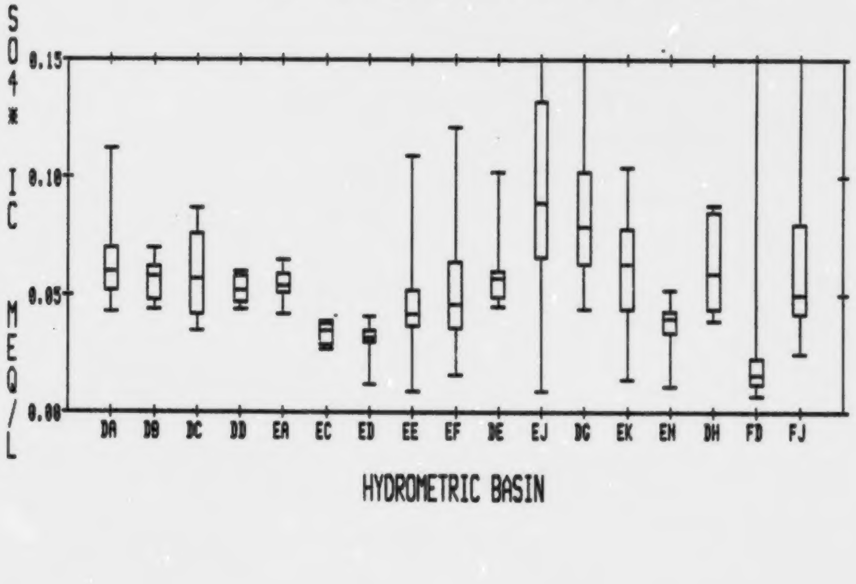
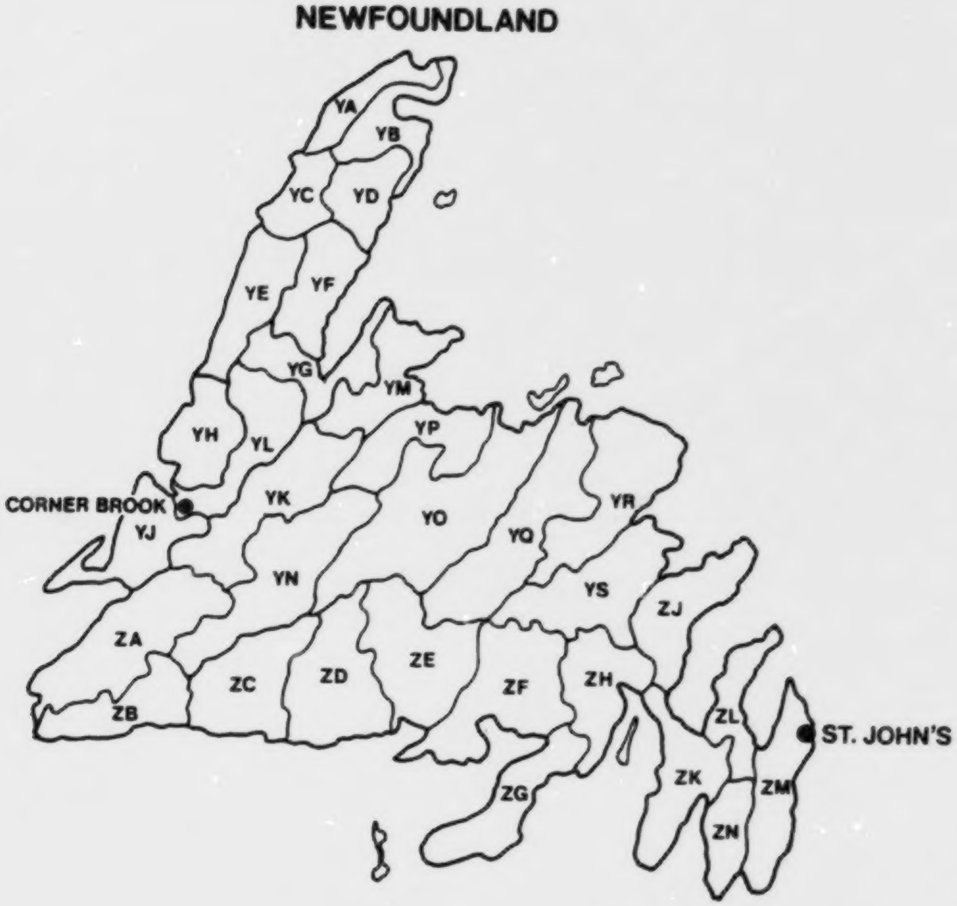
FIGURE 33 :BOXPLOT OF EXCESS SULPHATE (IC) CONCENTRATION FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS:




NEWFOUNDLAND
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ST. JOHN'S
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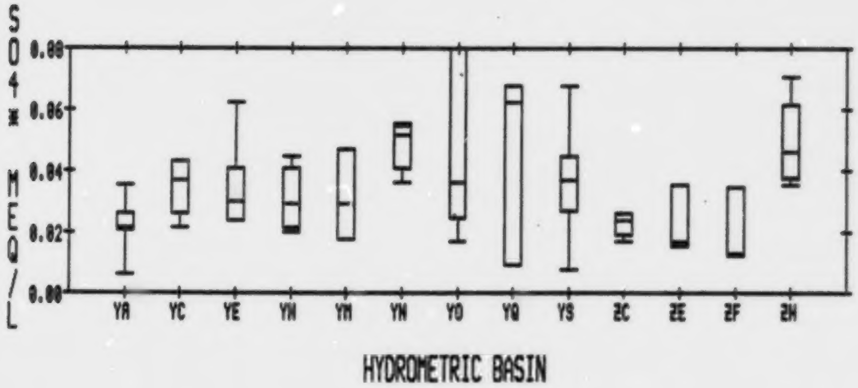
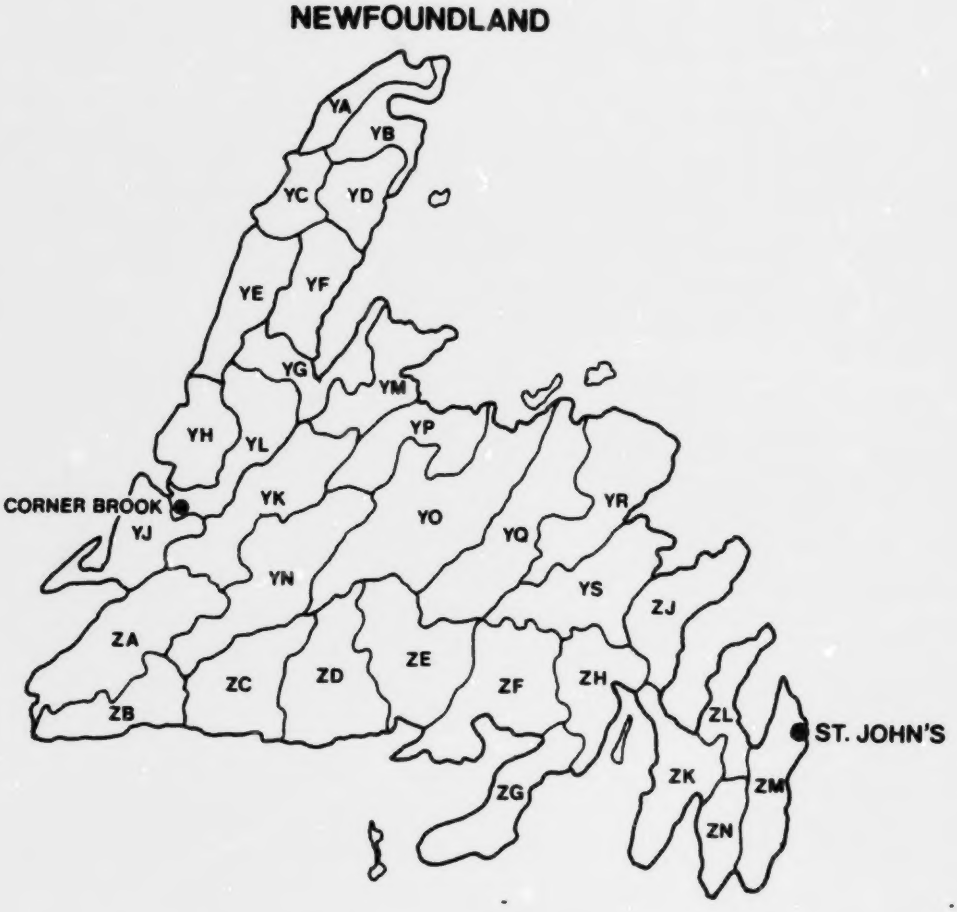
FIGURE 34 :BOXPLOT OF EXCESS SULPHATE (MTB FOR LAKES WITH COLOUR LE 30) CONCENTRATIONS FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.




NEWFOUNDLAND
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ZJ
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ZD
ZF
ZH
ZB
ZL
ST. JOHN'S
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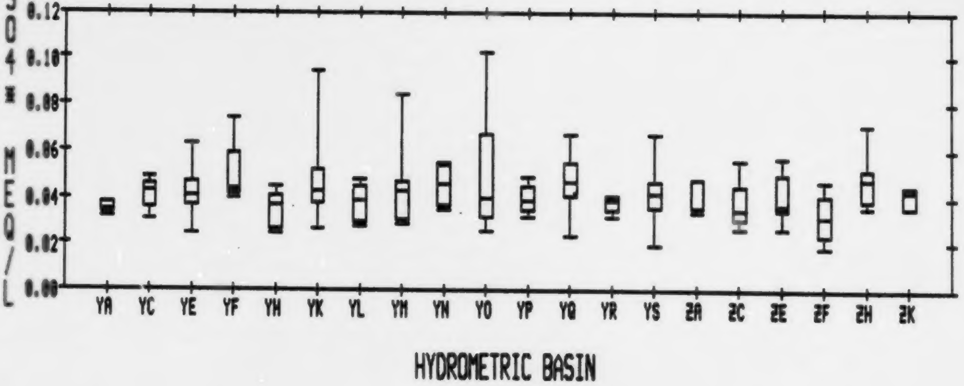
FIGURE 35 : BOXPLOT OF EXCESS SULPHATE (MTB) CONCENTRATION FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.



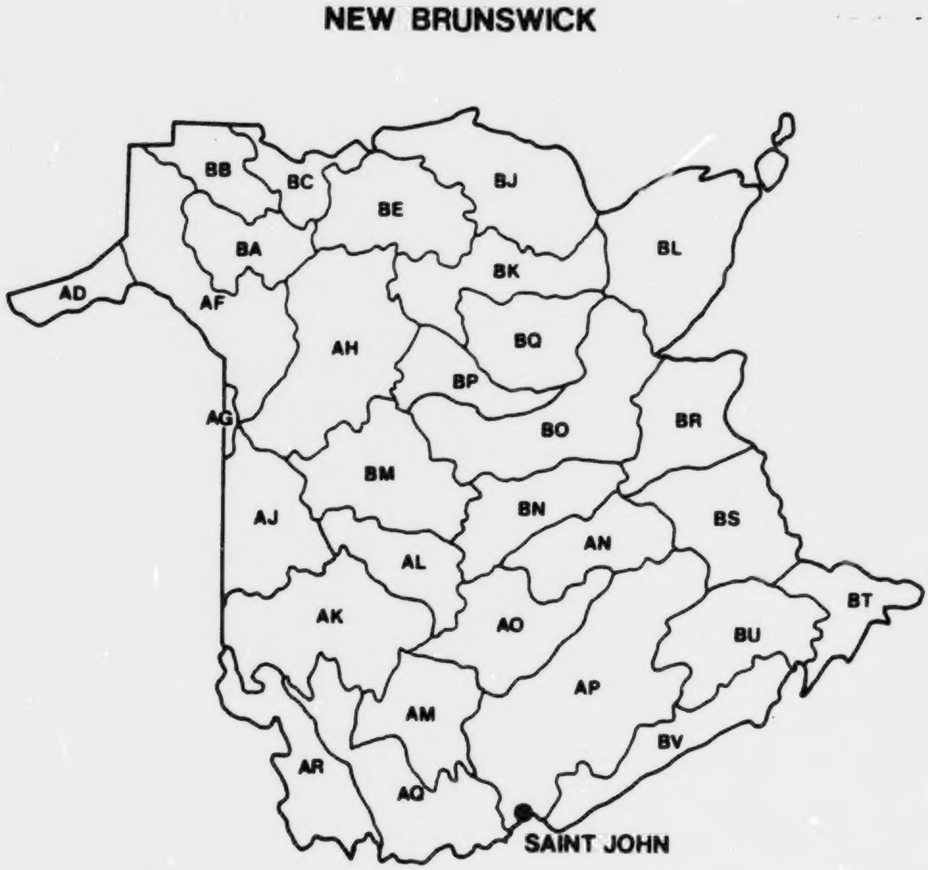

NEW BRUNSWICK
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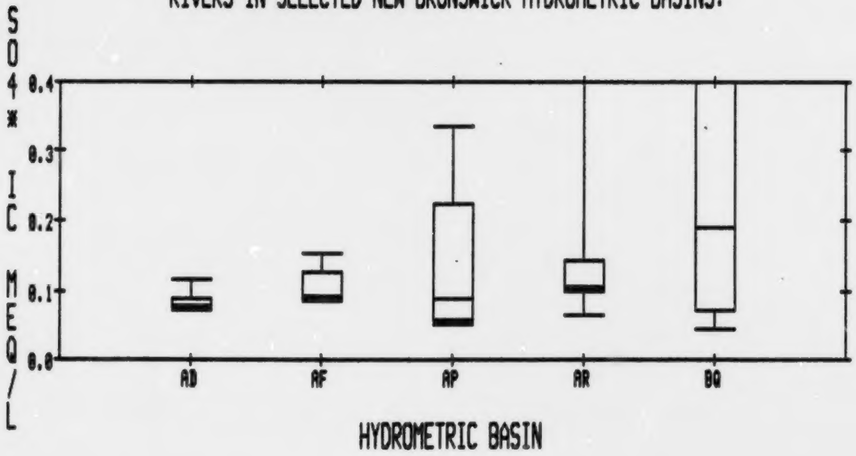
FIGURE 36 : BOXPLOT OF EXCESS SULPHATE (IC) CONCENTRATION FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.



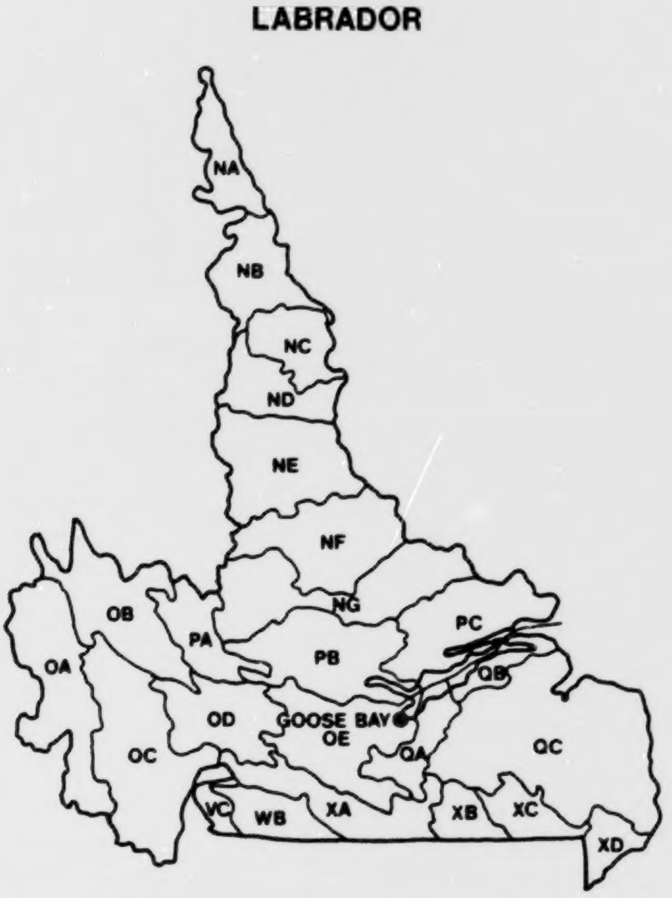

LABRADOR
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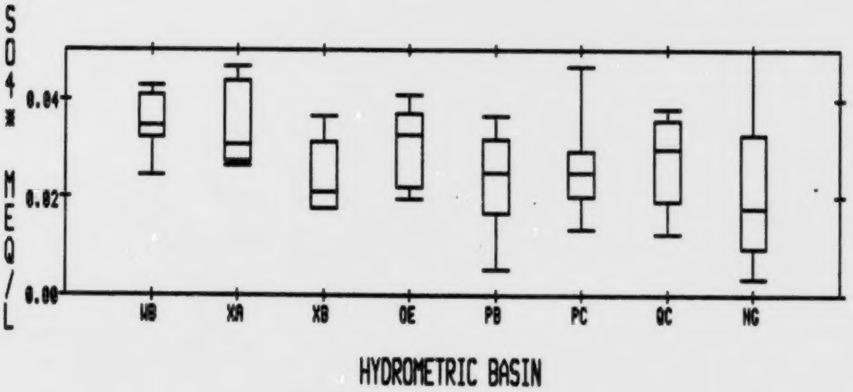
FIGURE 37:BOXPLOT OF EXCESS SULPHATE (MTB FOR LAKES WITH COLOUR LE 30) CONCENTRATION FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS.



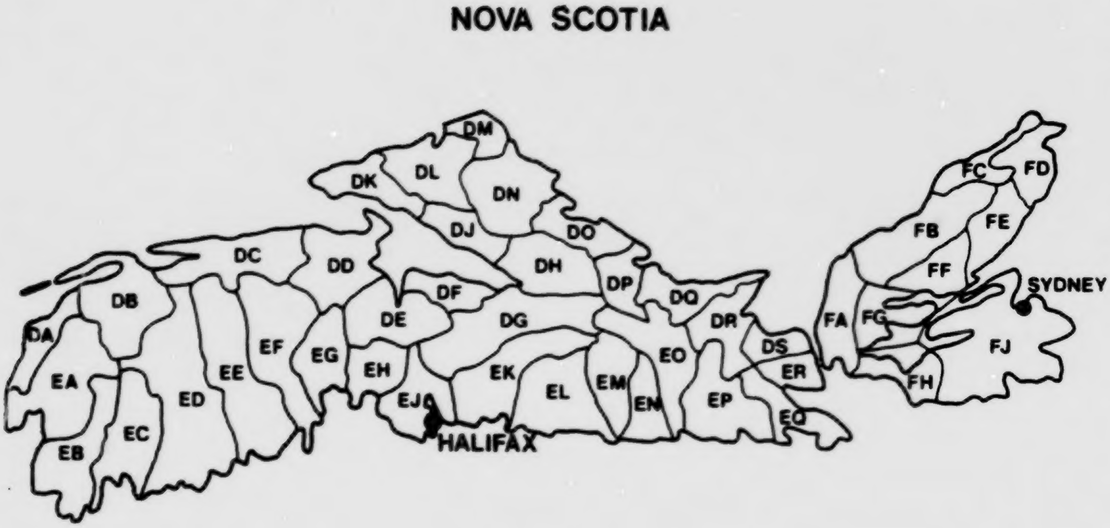

NOVA SCOTIA
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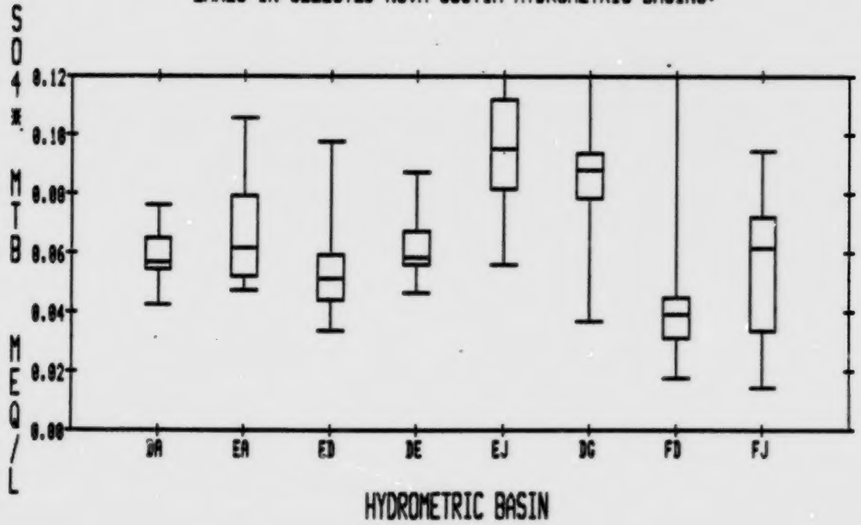
FIGURE 38 :BOXPLOT OF EXCESS SULPHATE (MTB) CONCENTRATION FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.



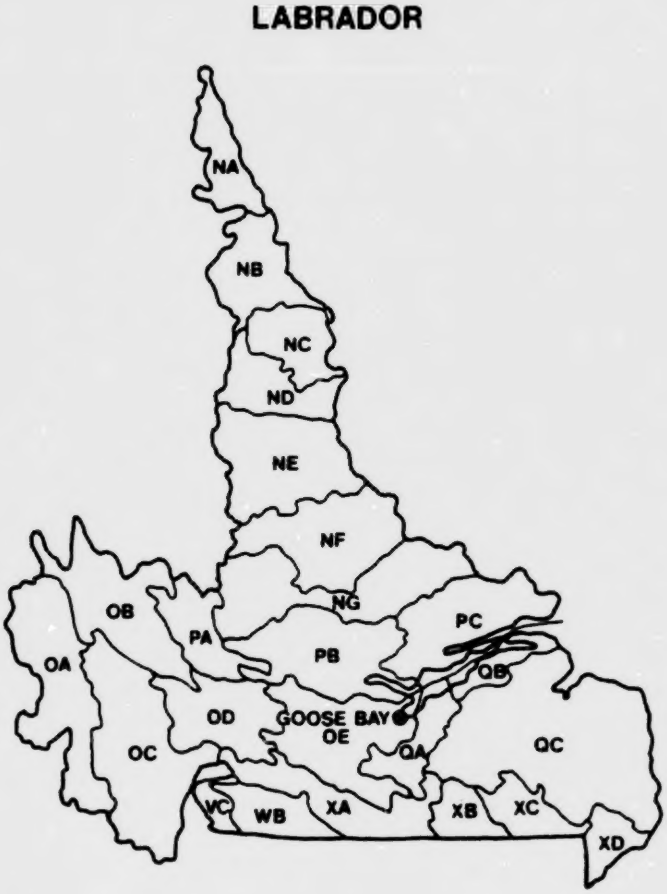

LABRADOR
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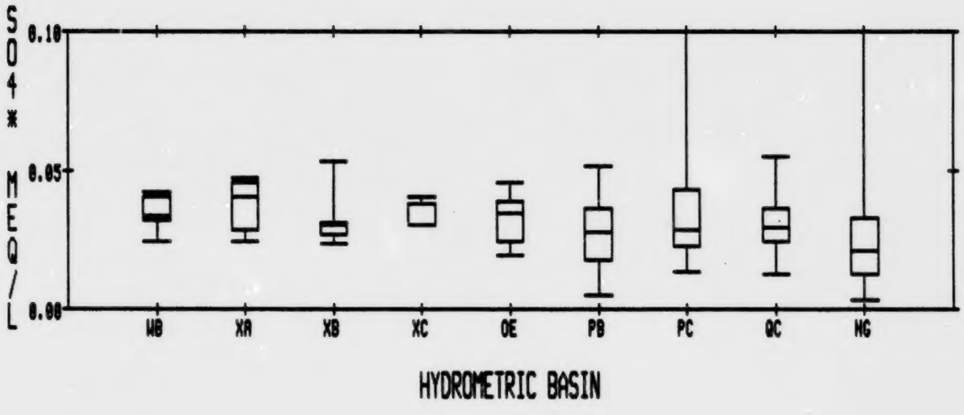
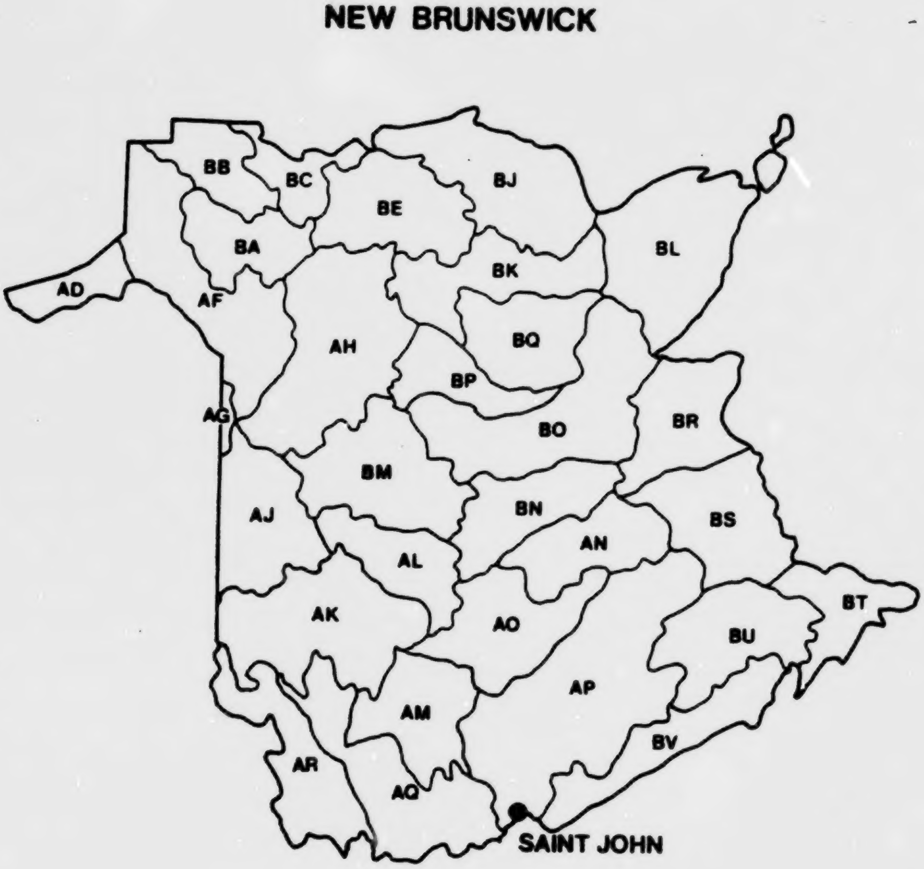
FIGURE 39 :BOXPLOT OF EXCESS SULPHATE (MTB) CONCENTRATION FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS.




NEW BRUNSWICK
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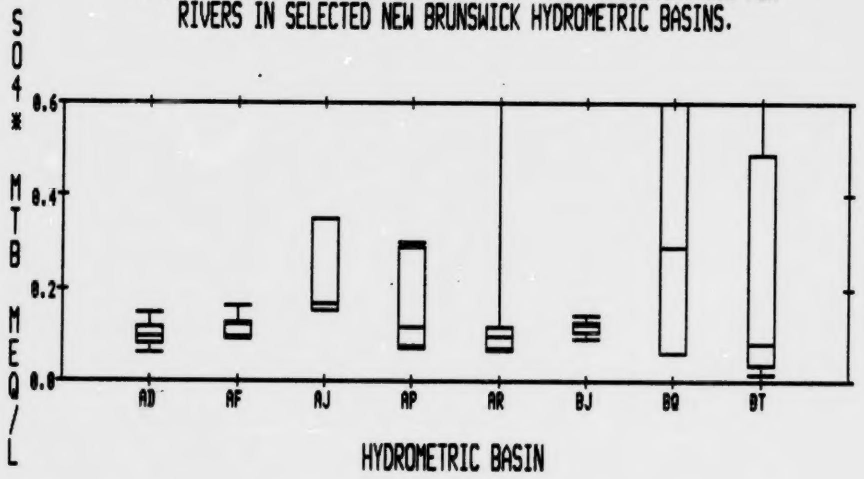
AQ
SAINT JOHN

FIGURE 40 :BOXPLOT OF EXCESS SULPHATE (MTB) CONCENTRATION FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.



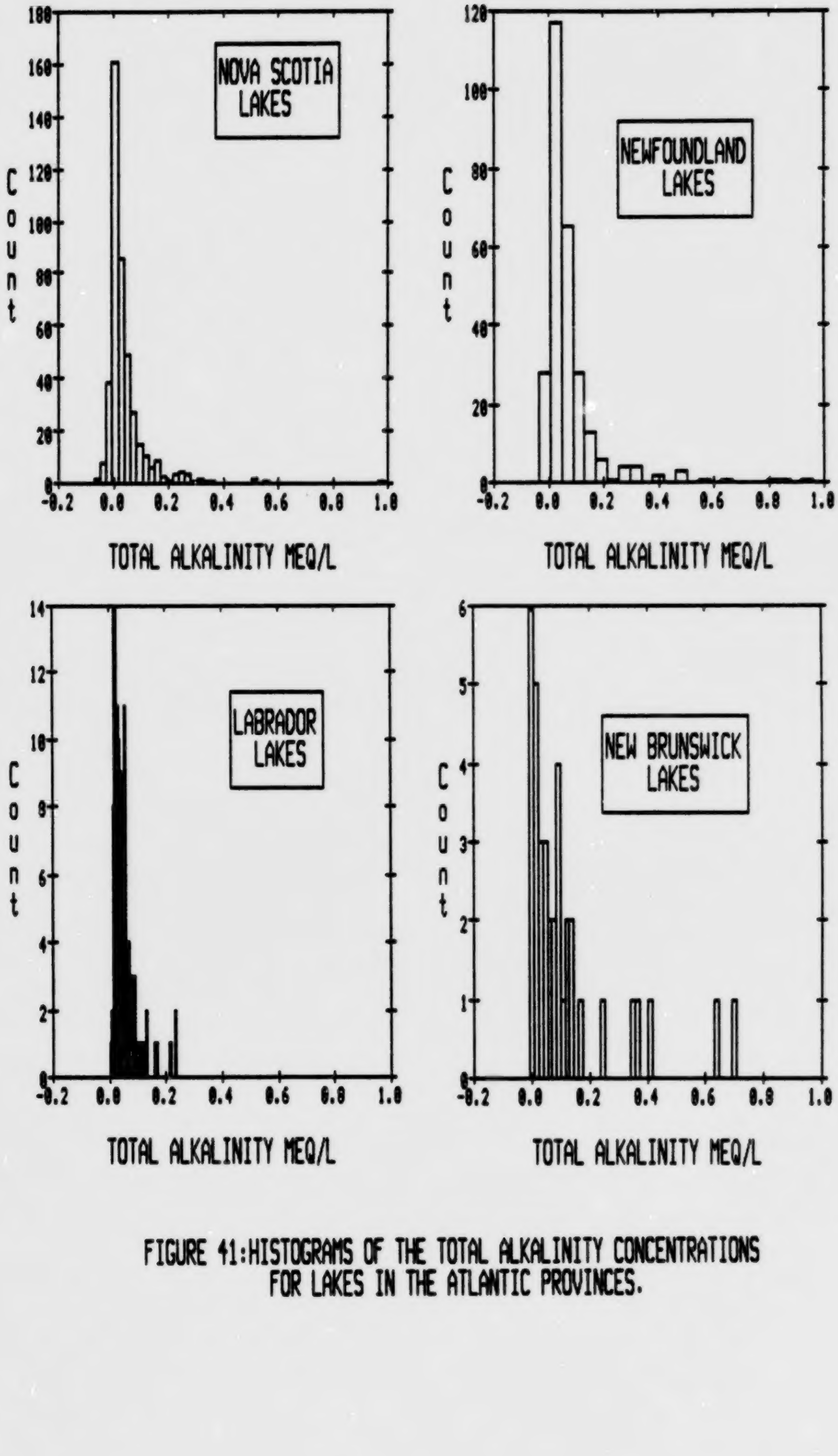


FIGURE 41:HISTOGRAMS OF THE TOTAL ALKALINITY CONCENTRATIONS FOR LAKES IN THE ATLANTIC PROVINCES.

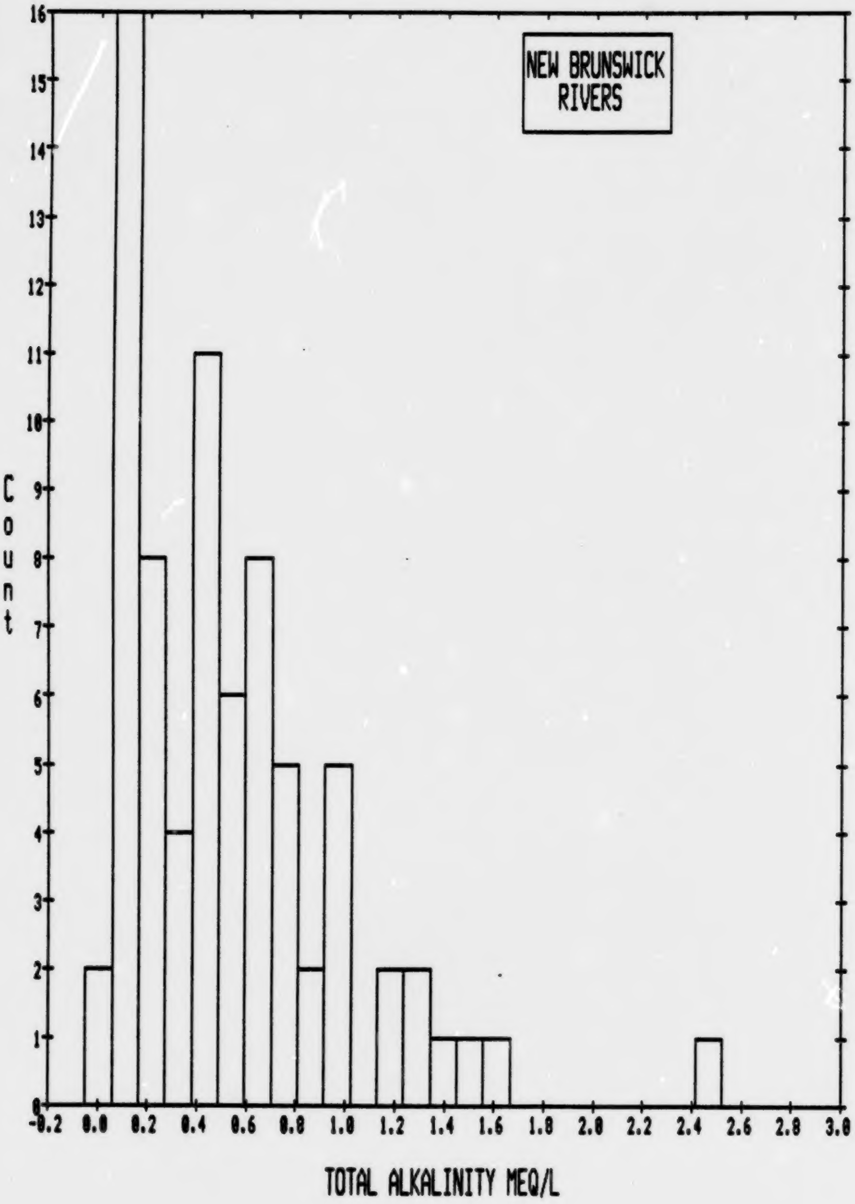


FIGURE 42:HISTOGRAM OF THE TOTAL ALKALINITY CONCENTRATIONS
FOR RIVERS IN NEW BRUNSWICK.

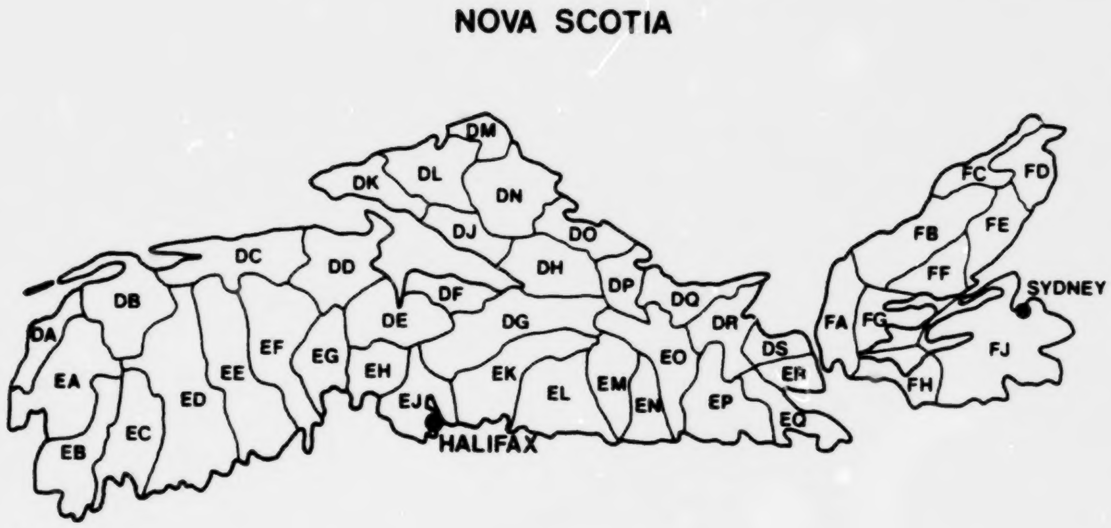
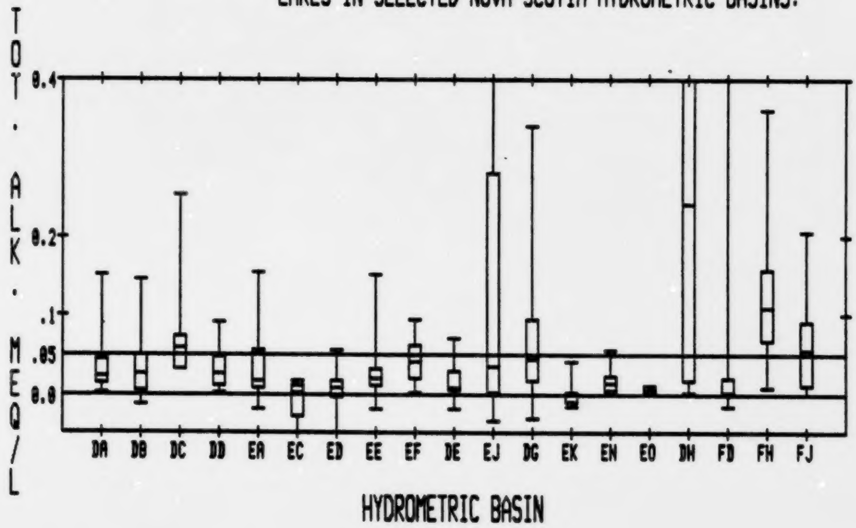
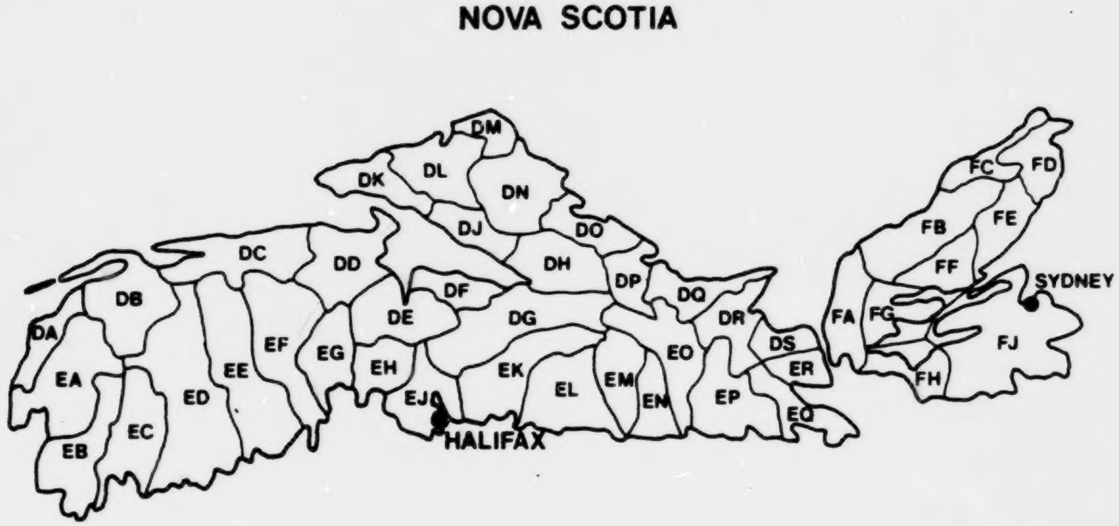

NOVA SCOTIA
DM
DK
DL
DN
DJ
DO
DC
DD
DH
DP
DQ
DB
DF
DA
DE
DG
DR
EF
EG
EH
EK
EO
DS
EA
EE
ER
ED
EJ
EL
EM
EN
EP
EQ
EC
EB
HALIFAX
FC
FD
FB
FE
FF
SYDNEY
FA
FG
FJ
FH

FIGURE 43:BOXPLOT OF TOTAL ALKALINITY CONCENTRATIONS FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.




NOVA SCOTIA
DM
DK
DL
DN
DJ
DO
DC
DD
DH
DP
DQ
SYDNEY
FC
FD
FB
FE
FF
DB
DF
DA
DE
DG
DR
DS
ER
FA
FG
FJ
FH
EA
EF
EE
EG
EH
EK
EL
EM
EN
EO
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EQ
ED
EJ
EC
EB
HALIFAX

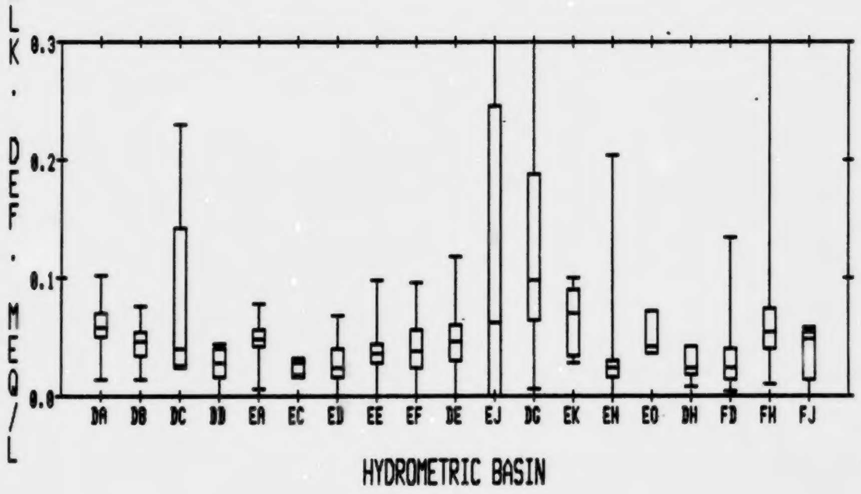


FIGURE 44 : BOXPLOT OF ALKALINITY DEFICIT (CA*+MG*-ALKALINITY) FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.

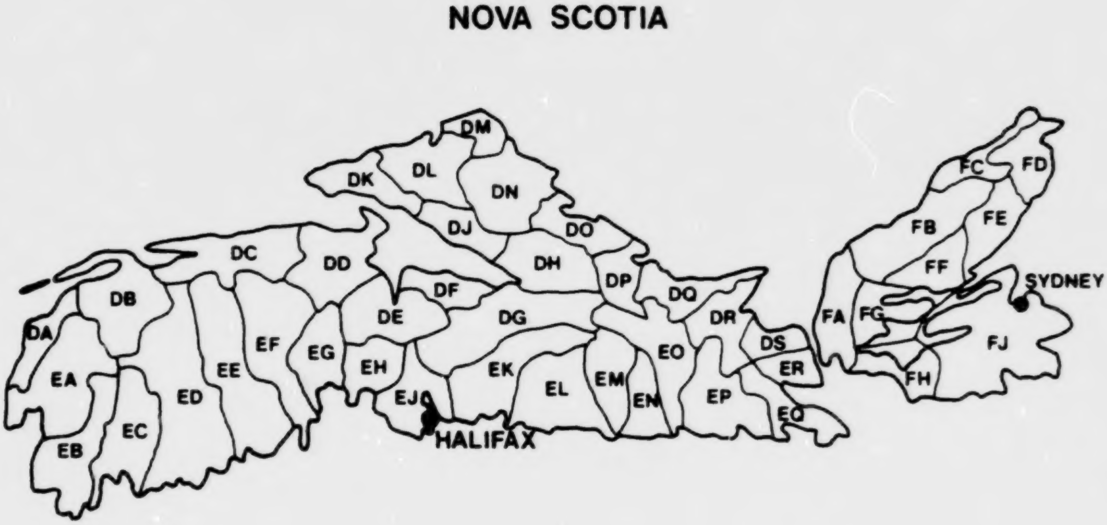
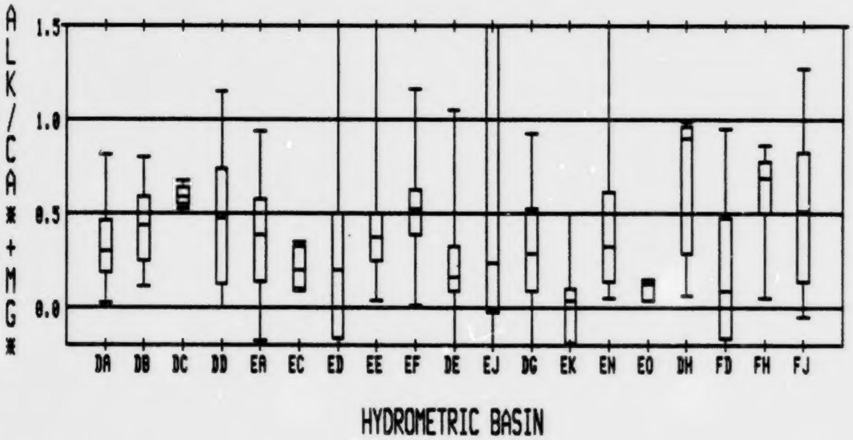

NOVA SCOTIA
DM
DL
DK
DN
DJ
DO
DC
DD
DH
DP
DQ
DB
DF
DE
DG
DR
DA
EF
EG
DS
EA
EE
EH
EK
EO
ER
ED
EJ
EL
EM
EN
EP
EC
EQ
EB
HALIFAX
FC
FD
FB
FE
FF
SYDNEY
FA
FG
FJ
FH

FIGURE 45 :BOXPLOT OF THE RATIO OF ALKALINITY TO EXCESS CALCIUM AND MAGNESIUM FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.



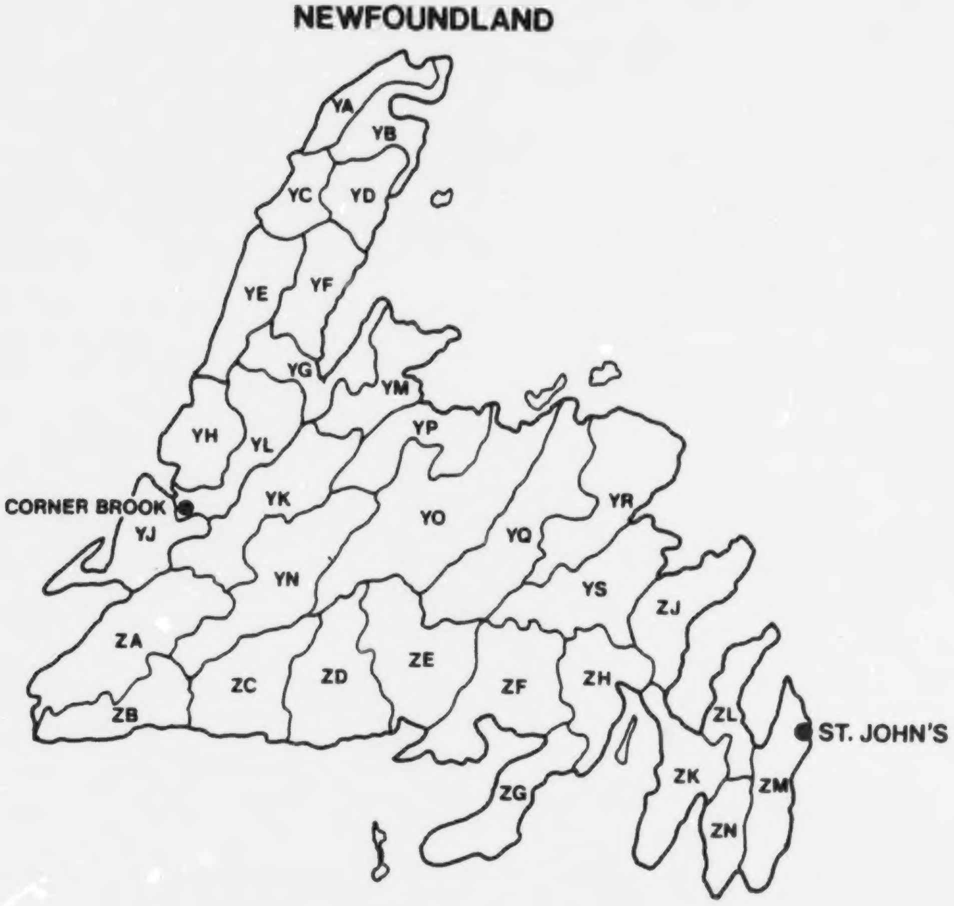
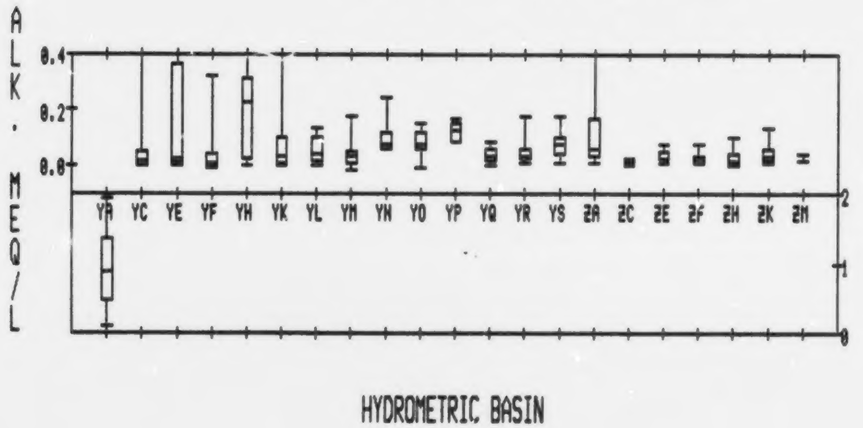

NEWFOUNDLAND
YA
YB
YC
YD
YE
YF
YG
YM
YH
YL
YP
CORNER BROOK
YK
YJ
YO
YQ
YR
YN
YS
ZJ
ZA
ZE
ZC
ZD
ZF
ZH
ZB
ZL
ST. JOHN'S
ZG
ZK
ZM
ZN

FIGURE 46 : BOXPLOT OF TOTAL ALKALINITY FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.



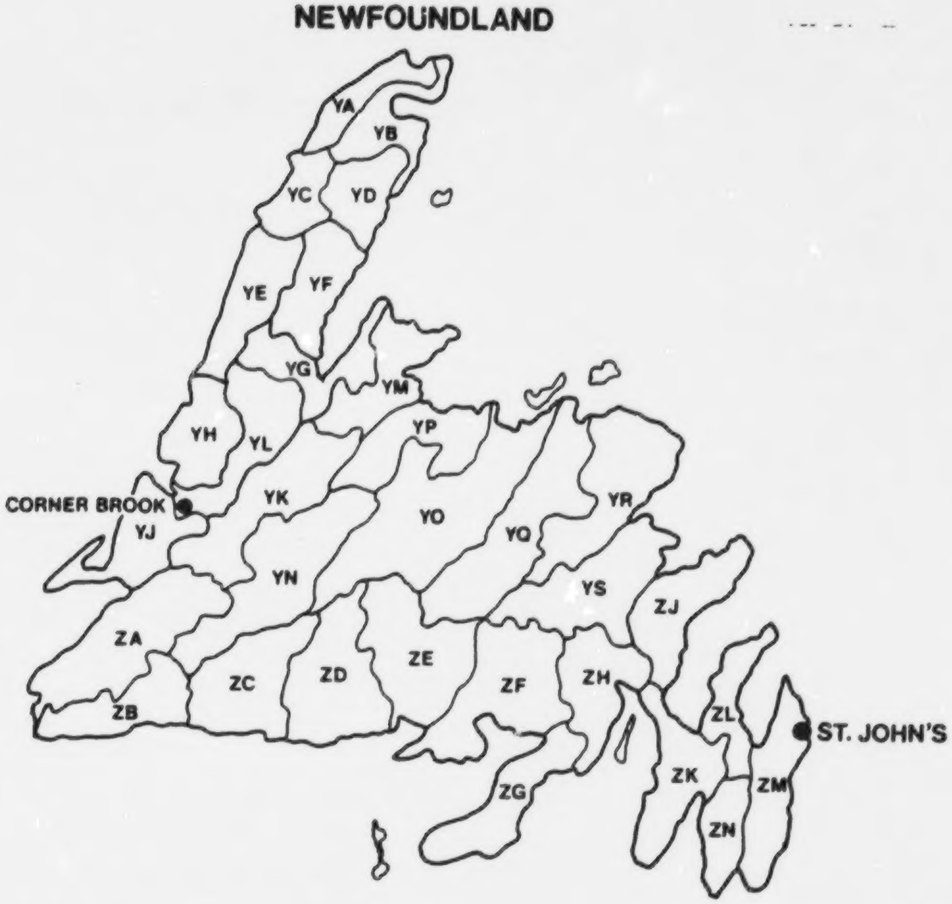
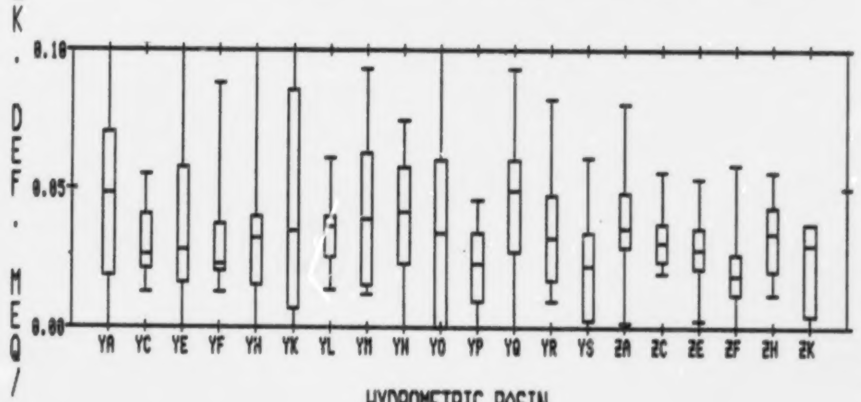

NEWFOUNDLAND
YA
YB
YC
YD
YE
YF
YG
YM
YH
YL
YP
CORNER BROOK
YK
YJ
YO
YQ
YR
YN
YS
ZJ
ZA
ZE
ZC
ZD
ZF
ZH
ZB
ZL
ST. JOHN'S
ZK
ZM
ZG
ZN

FIGURE 47 : BOXPLOT OF ALKALINITY DEFICIT (CA*+MG*-ALK) FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.



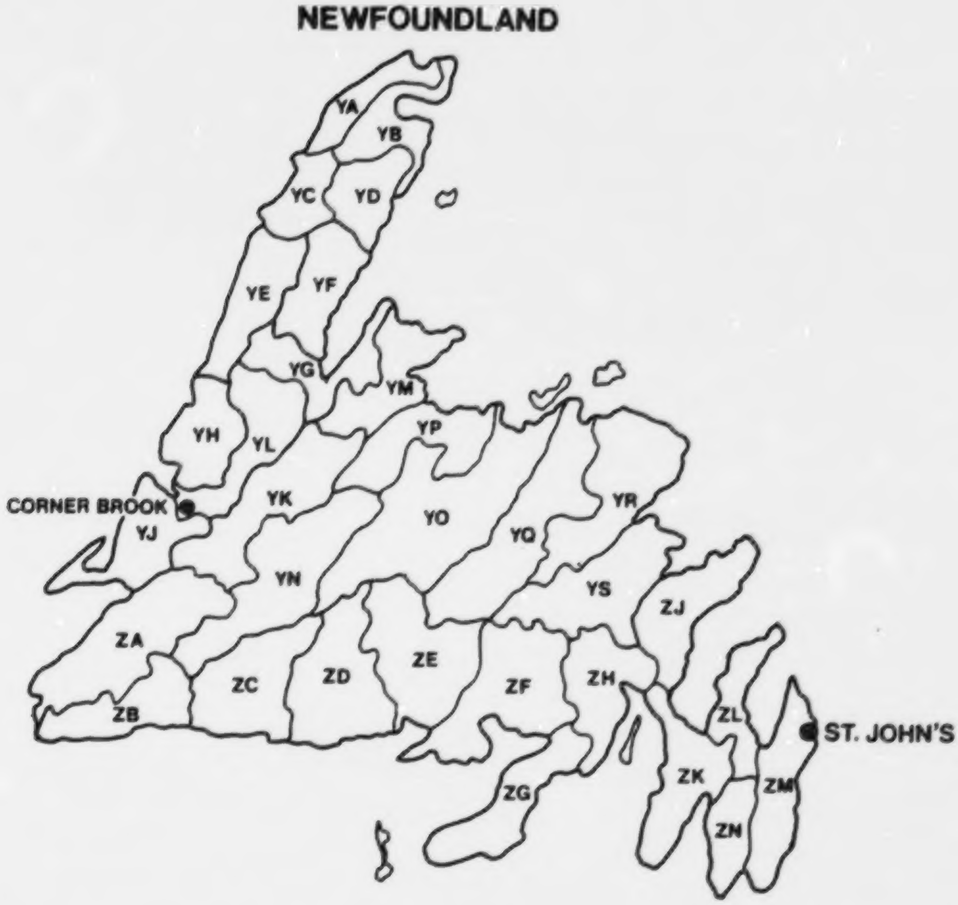
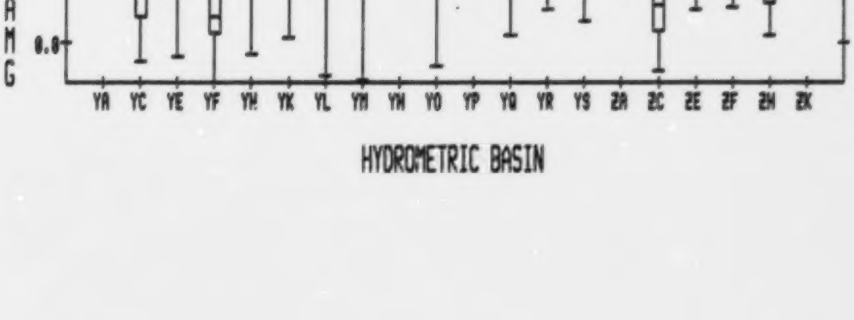

NEWFOUNDLAND
YA
YB
YC
YD
YE
YF
YG
YM
YH
YL
YP
CORNER BROOK
YJ
YK
YO
YR
YQ
YN
YS
ZJ
ZA
ZE
ZC
ZD
ZF
ZH
ZB
ZL
ST. JOHN'S
ZK
ZM
ZG
ZN

FIGURE 48 : BOXPLOT OF THE RATIO OF ALKALINITY TO EXCESS CALCIUM AND MAGNESIUM FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS



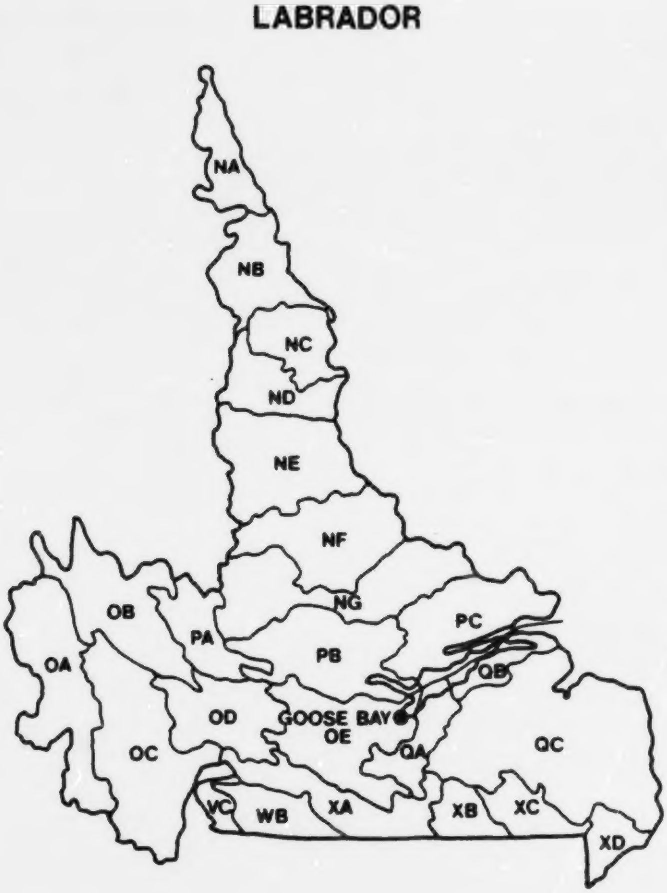
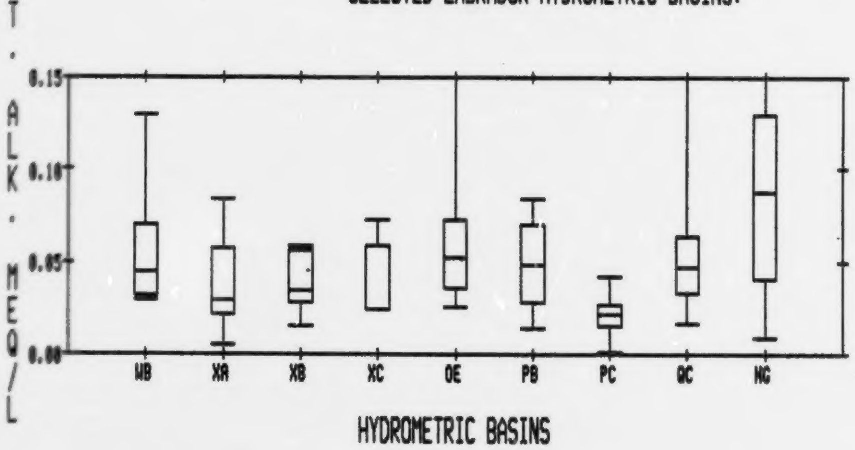

LABRADOR
NA
NB
NC
ND
NE
NF
NG
OB
PA
PC
OA
PB
QB
OD
GOOSE BAY
OE
QC
OC
QA
VC
WB
XA
XB
XC
XD

FIGURE 49 :BOXPLOT OF TOTAL ALKALINITY FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS.



LABRADOR

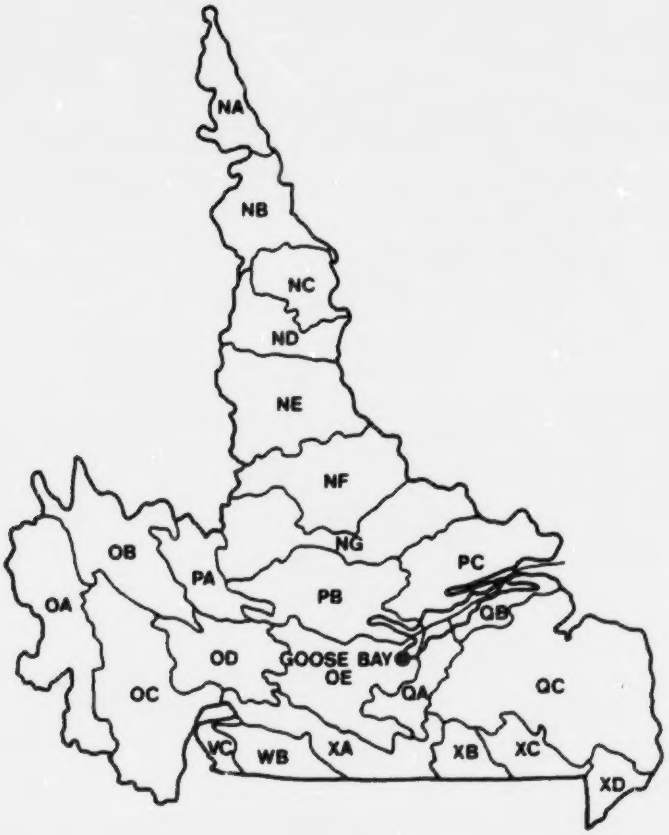
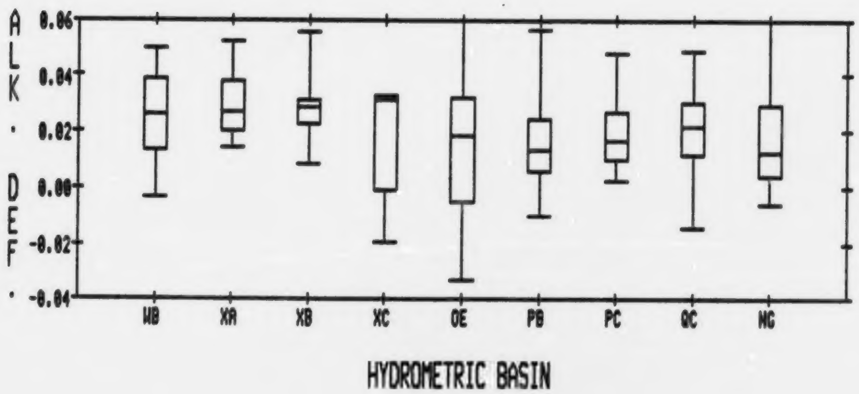
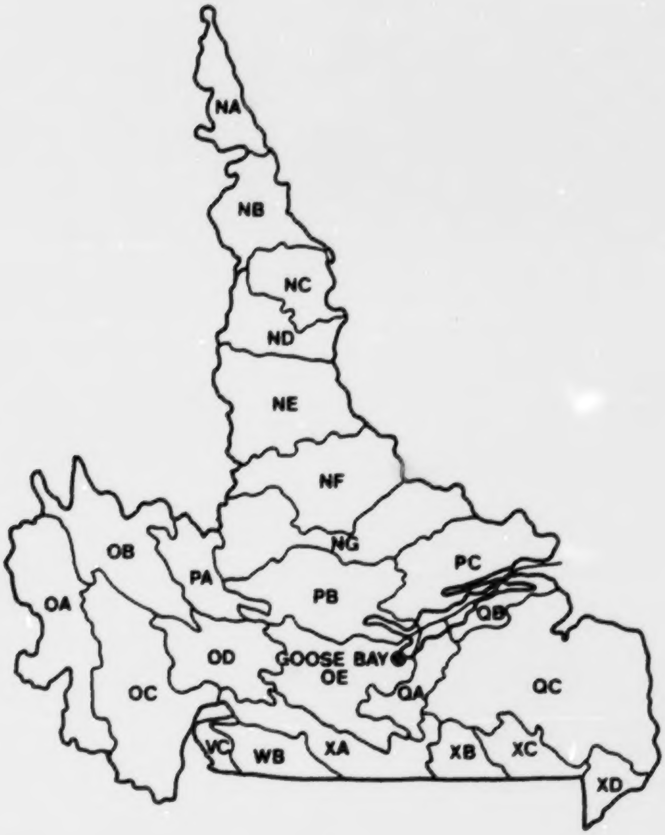

NA
NB
NC
ND
NE
NF
NG
OB
PA
PC
OA
PB
QB
OD
GOOSE BAY
OE
QA
QC
OC
VC
WB
XA
XB
XC
XD

FIGURE 50 :BOXPLOT OF ALKALINITY DEFICIT (CA*+MG*-ALK MEQ/L)
FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS



LABRADOR


NA
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NE
NF
NG
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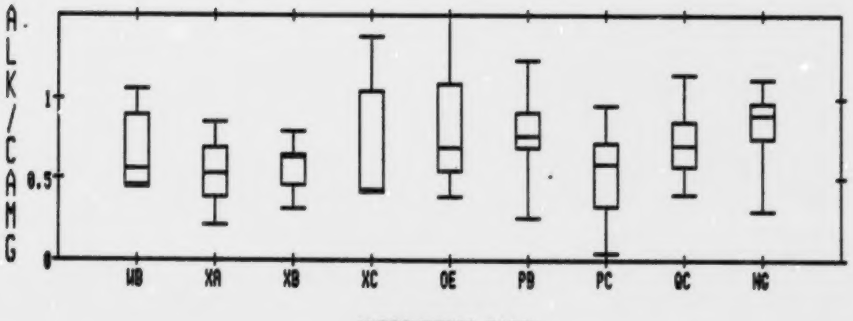
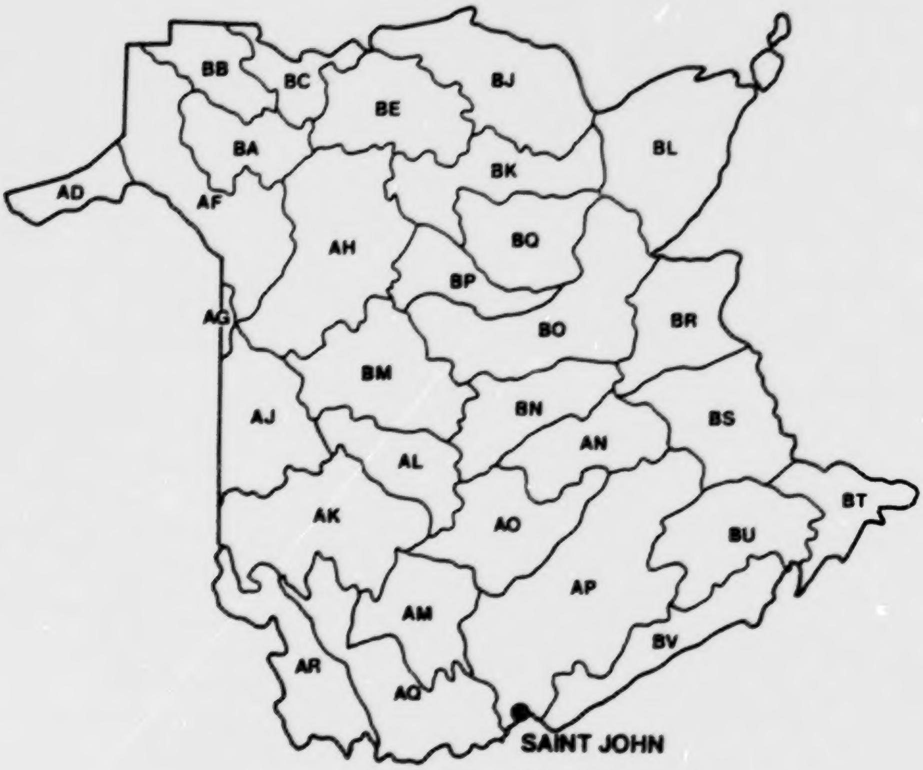
PA
PB
OA
QB
OD
GOOSE BAY
OE
QA
QC
OC
VC
WB
XA
XB
XC
XD

FIGURE :BOXPLOT OF THE RATIO OF ALKALINITY TO EXCESS CALCIUM AND MAGNESIUM FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS.




NEW BRUNSWICK
BB
BC
BJ
BE
BL
BA
BK
AD
AF
BQ
AH
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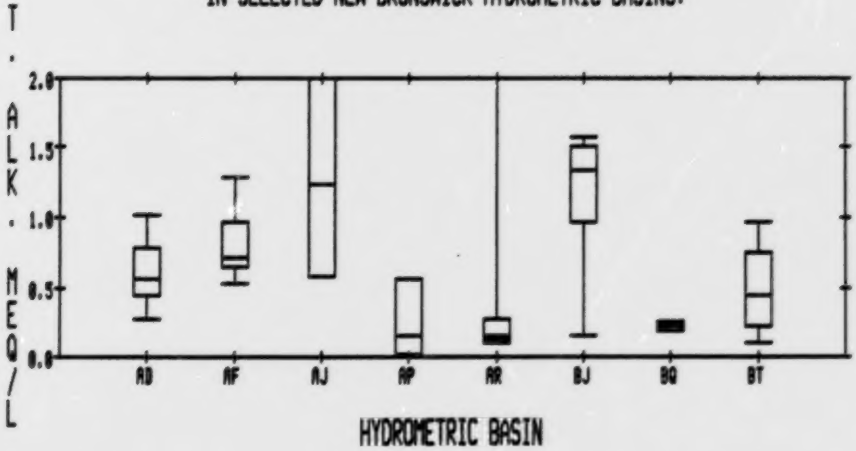
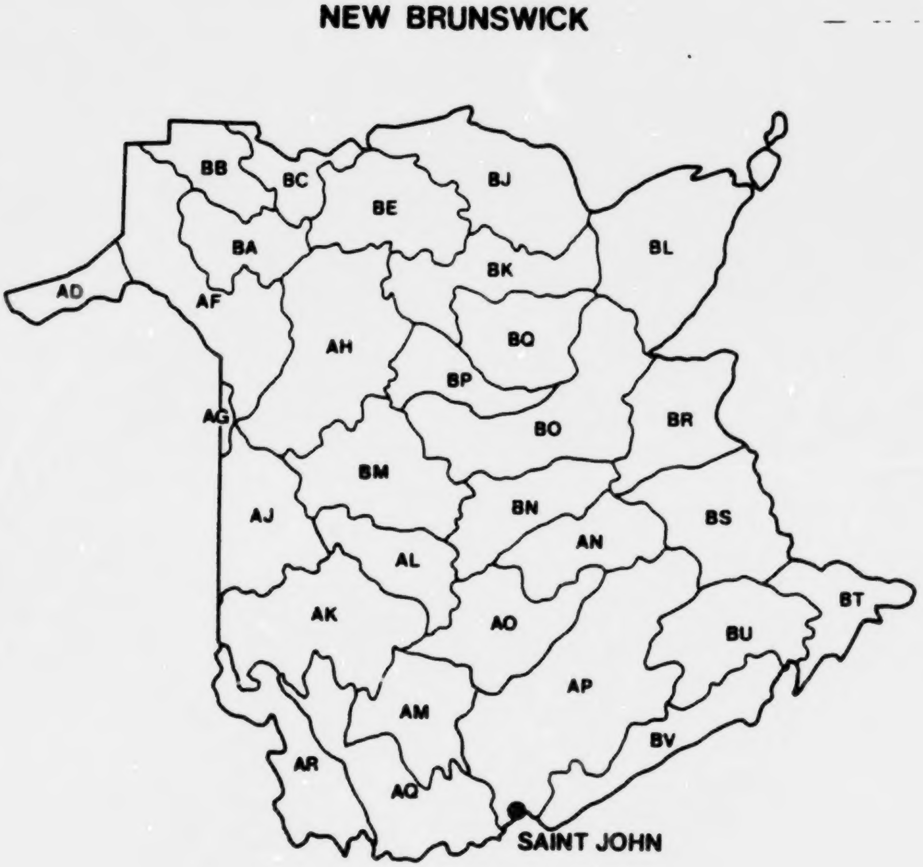
BO
BR
BM
BN
AJ
BS
AN
AL
BT
AK
AO
BU
AP
AM
BV
AR
AQ
SAINT JOHN

FIGURE 52 :BOXPLOT OF TOTAL ALKALINITY CONCENTRATION FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.




NEW BRUNSWICK
BB
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BJ
BE
BA
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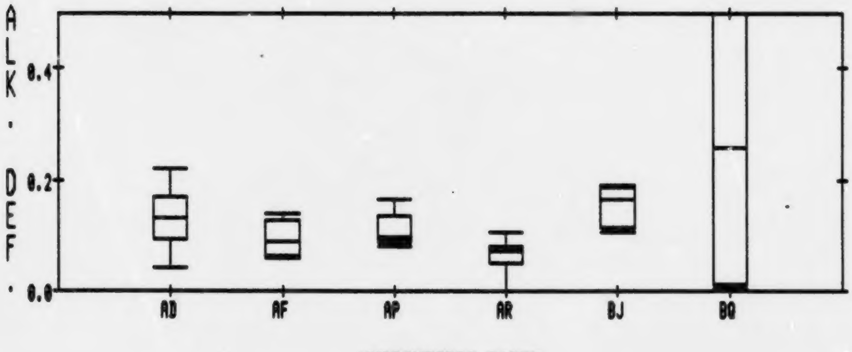
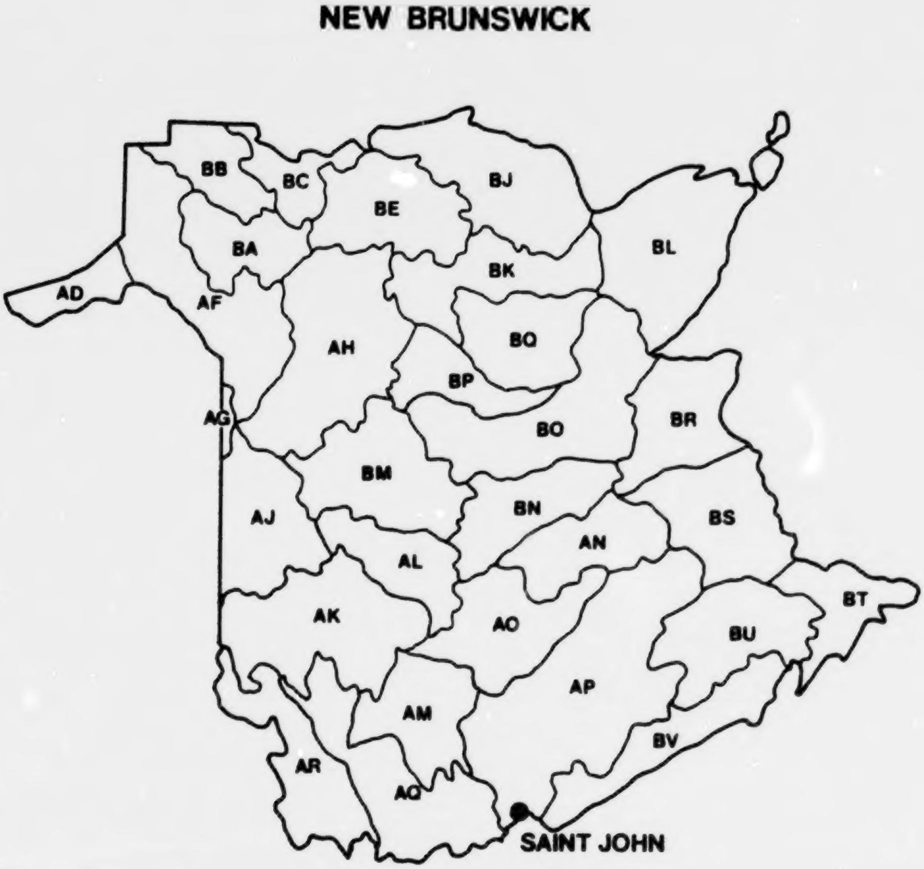
BK
AD
AF
BQ
AH
BP
AG
BO
BR
BM
AJ
BN
BS
AN
AL
BT
AK
AO
BU
AP
AM
BV
AR
AQ
SAINT JOHN

FIGURE :BOXPLOT OF ALKALINITY DEFICIT (CA*+MG*-ALK MEQ/L)
FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.




NEW BRUNSWICK
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BE
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BK
AD
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BQ
AH
BP
AG
BO
BR
BM
AJ
BN
BS
AN
AL
BT
AK
AO
BU
AP
AM
BV
AR
AQ
SAINT JOHN

FIGURE 54 :BOXPLOT OF THE RATIO OF ALKALINITY TO EXCESS CALCIUM AND MAGNESIUM FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.

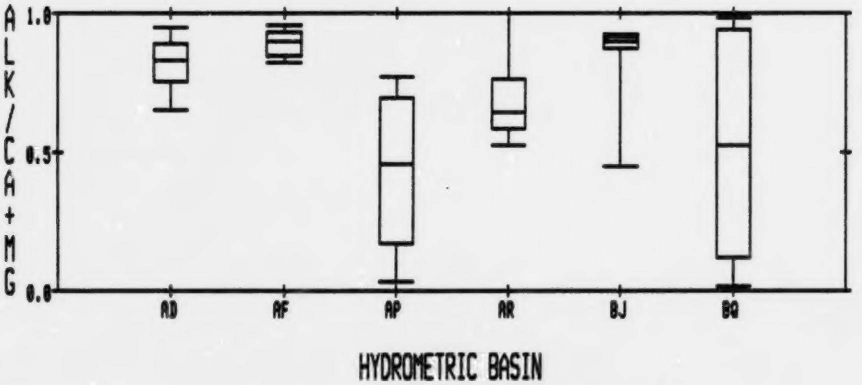
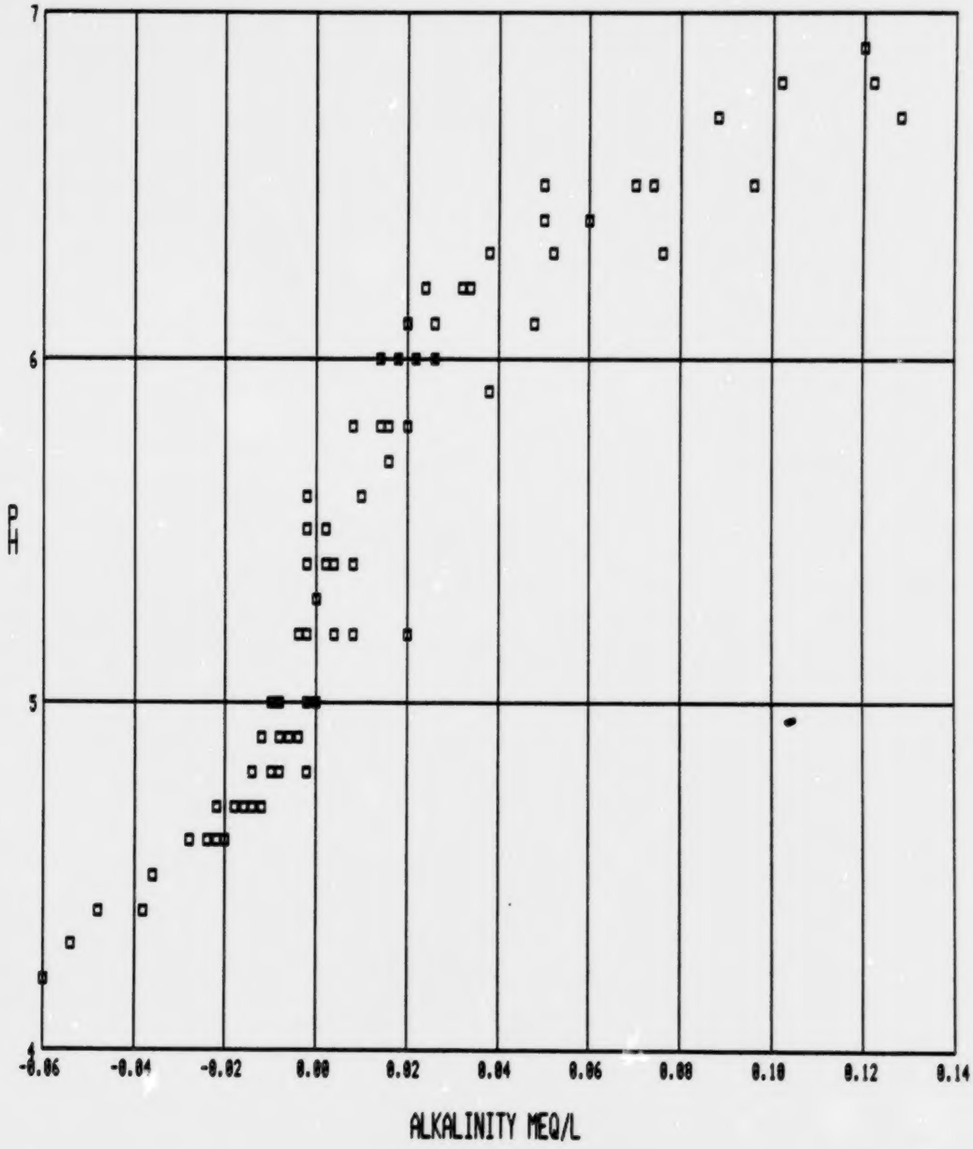


FIGURE 55 :RELATIONSHIP BETWEEN PH AND ALKALINITY FOR SELECTED LAKES IN NOVA SCOTIA.



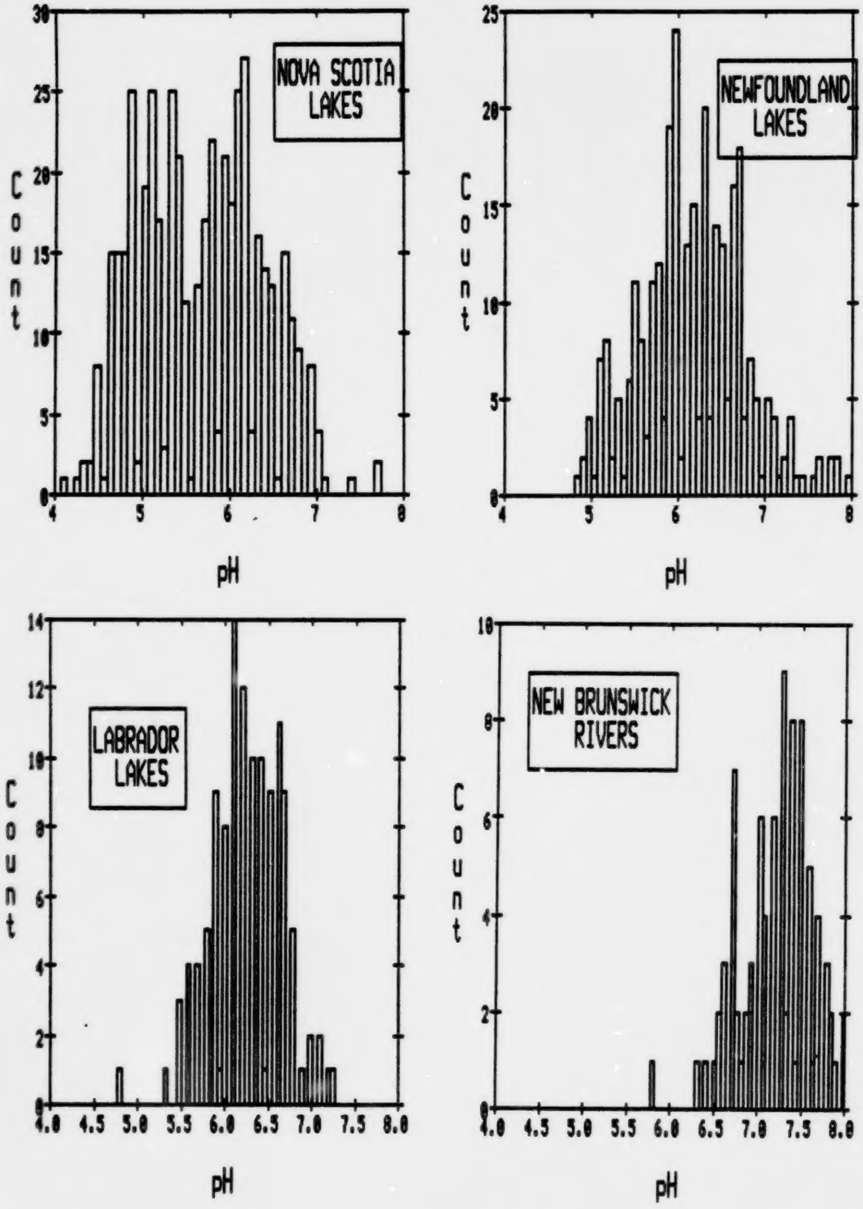


FIGURE 56:HISTOGRAMS OF pH FOR LAKES AND RIVERS IN THE ATLANTIC PROVINCES.

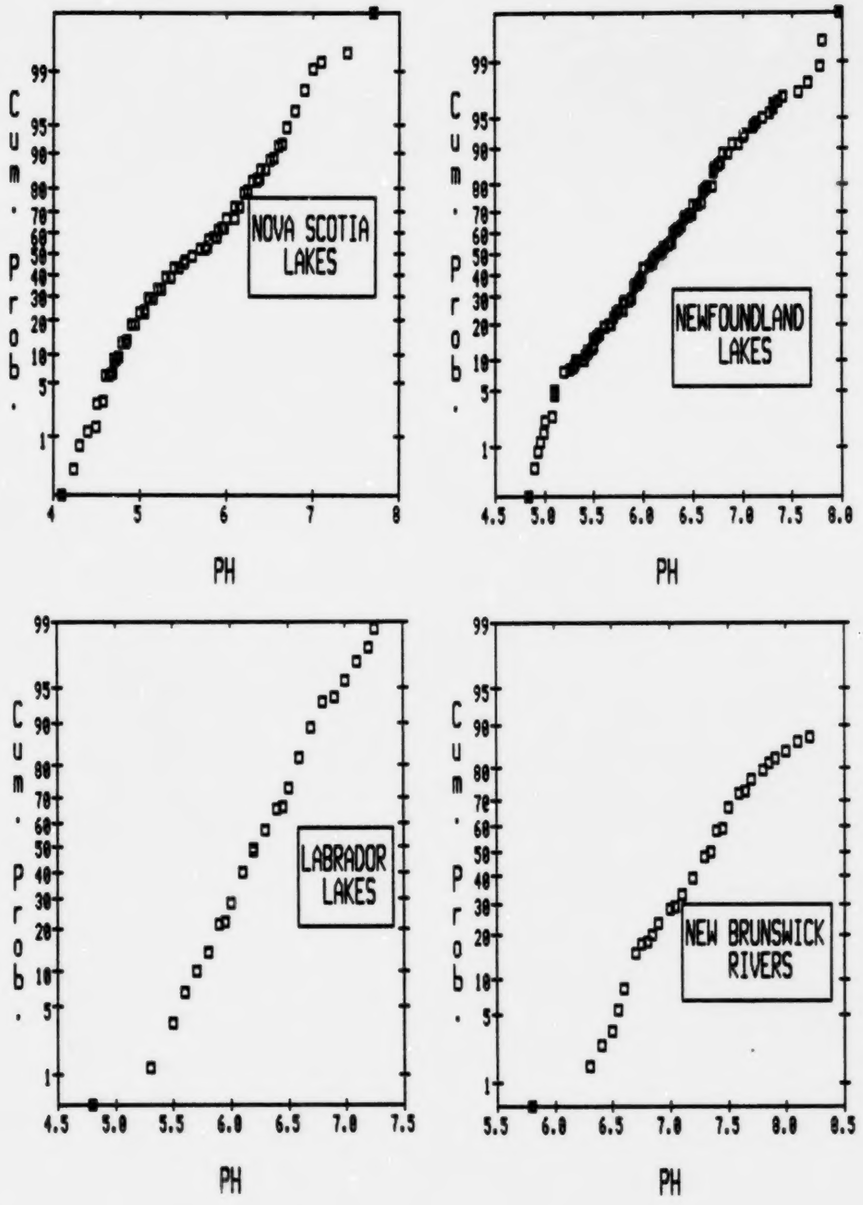
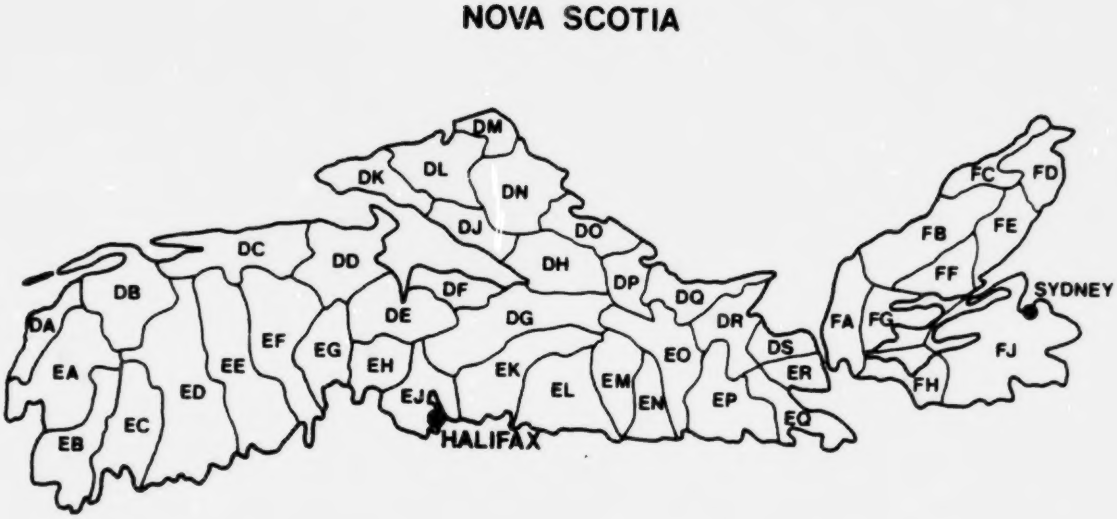


FIGURE 57:CUMULATIVE PROBABILITY PLOTS OF pH FOR LAKES AND RIVERS IN THE ATLANTIC PROVINCES.


NOVA SCOTIA
DM
DK
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DJ
DO
DC
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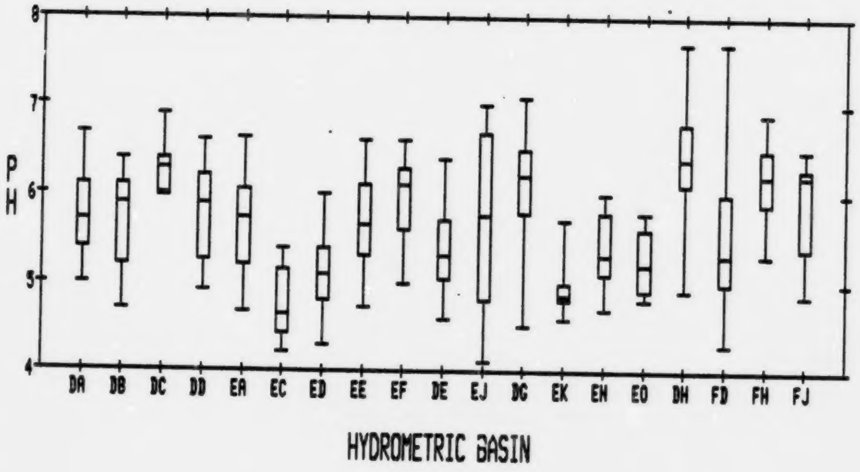
DH
DF
DP
DQ
DB
DA
DE
DG
DR
EA
EF
EE
EG
EH
EK
EO
DS
ER
ED
EJ
EL
EM
EN
EP
EQ
EC
EB
HALIFAX
FC
FD
FB
FE
FF
SYDNEY
FA
FG
FJ
FH

FIGURE 58: BOXPLOT OF PH FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.



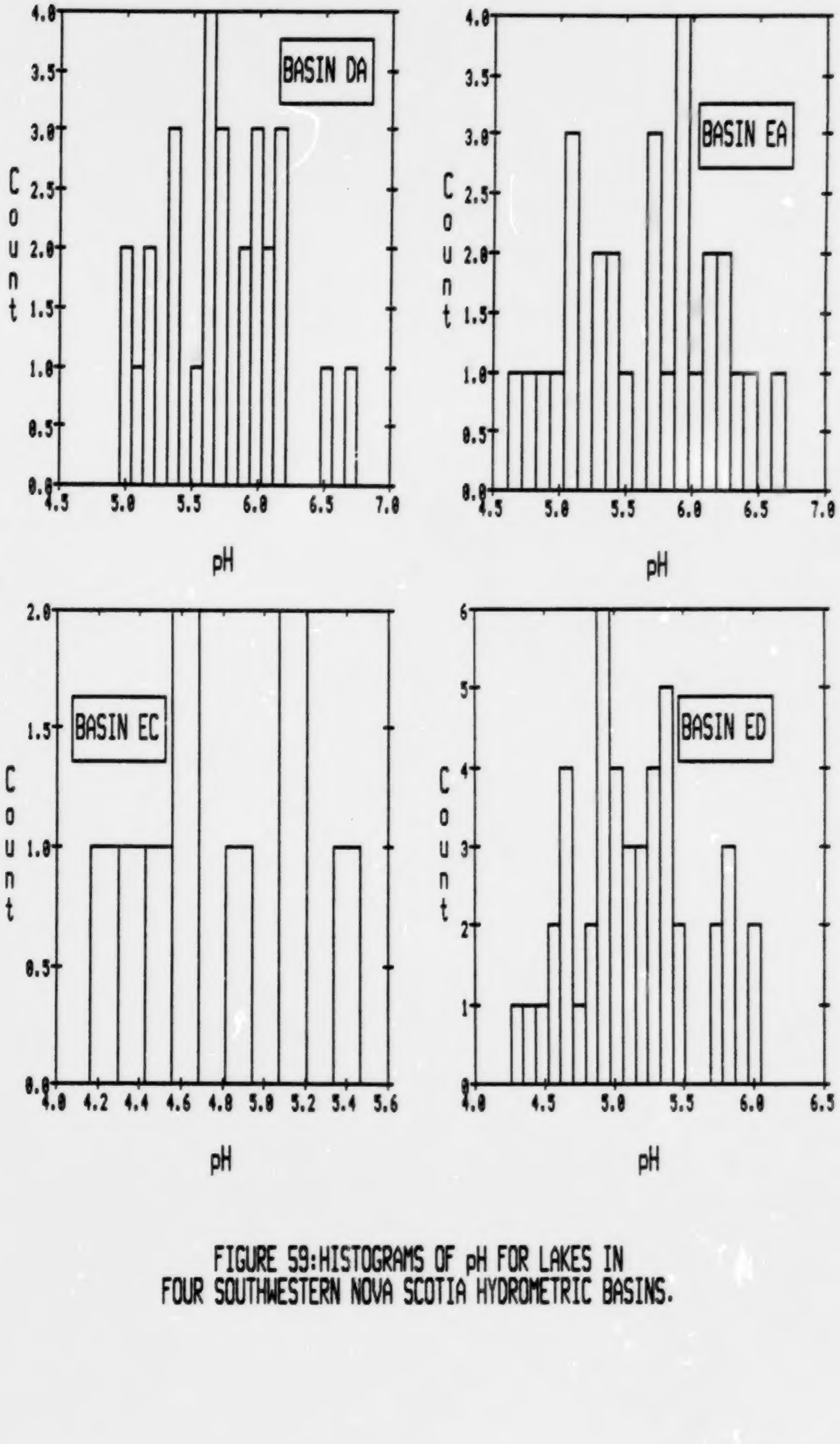


FIGURE 59:HISTOGRAMS OF pH FOR LAKES IN
FOUR SOUTHWESTERN NOVA SCOTIA HYDROMETRIC BASINS.

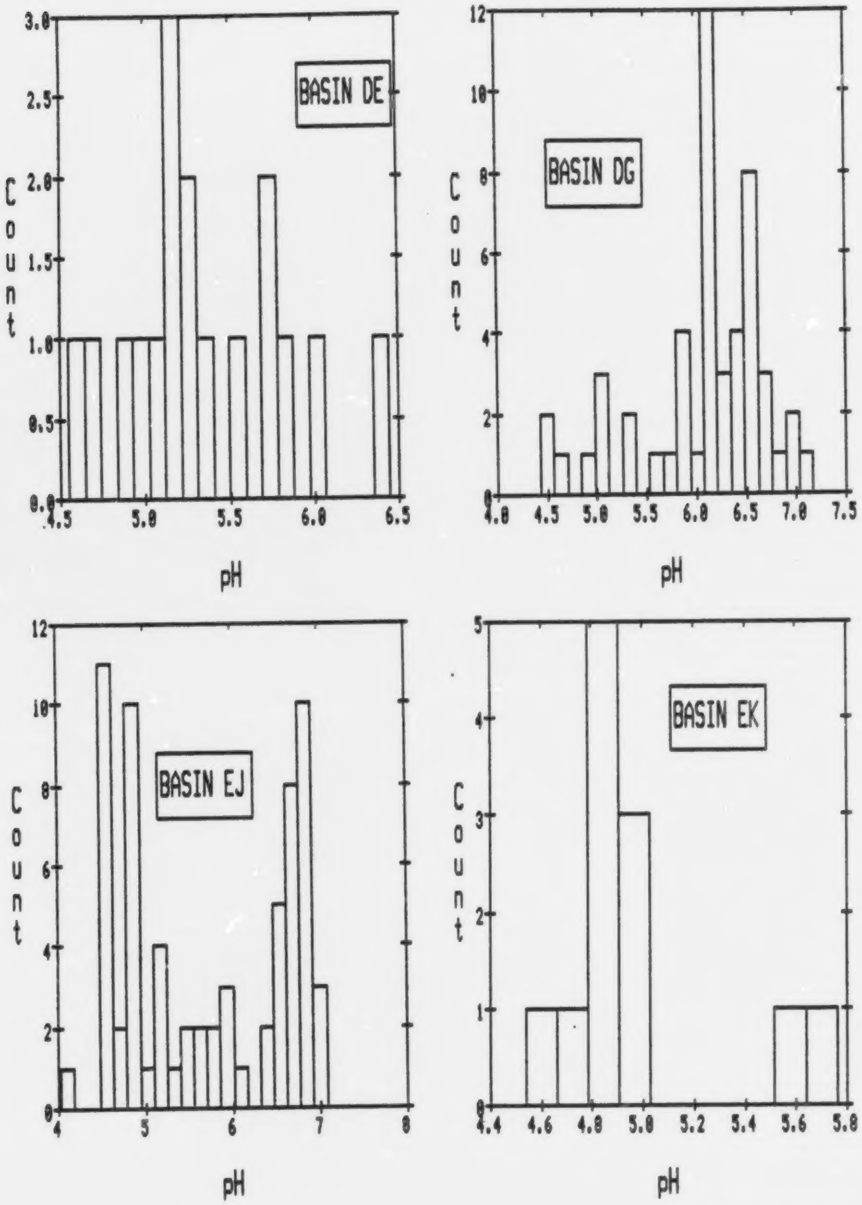


FIGURE 60:HISTOGRAMS OF pH FOR LAKES IN FOUR NOVA SCOTIA HYDROMETRIC BASINS LOCATED NEAR HALIFAX.

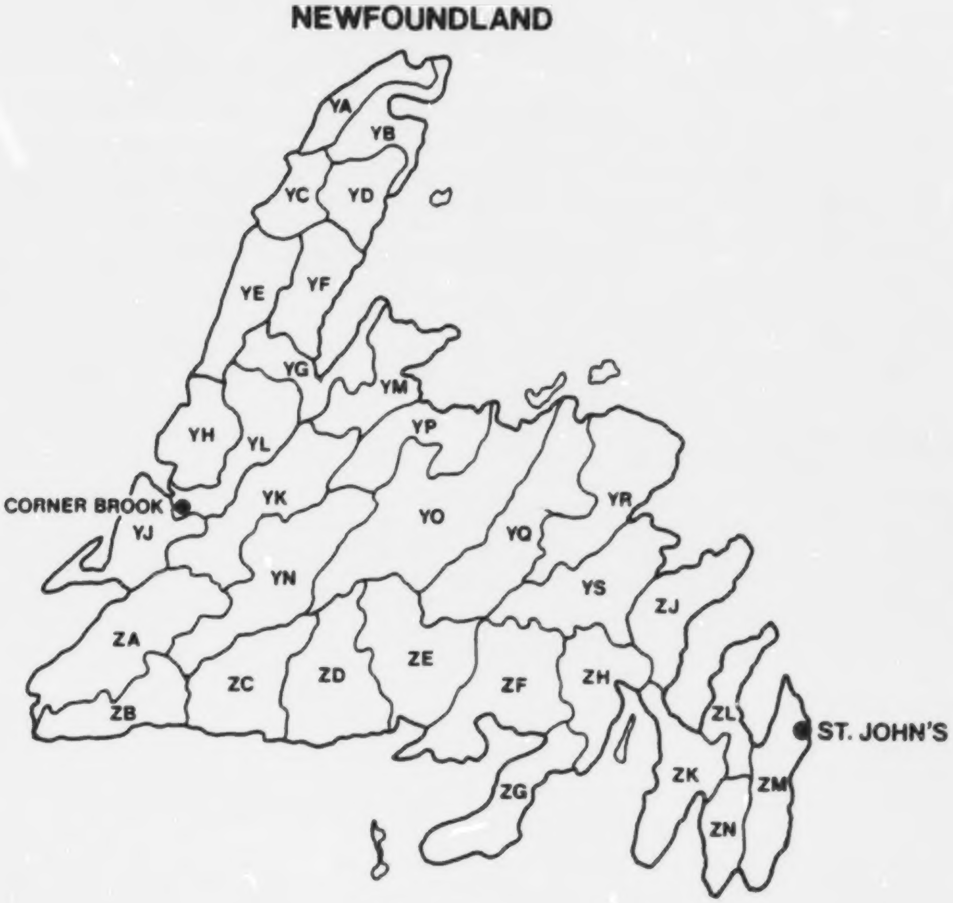
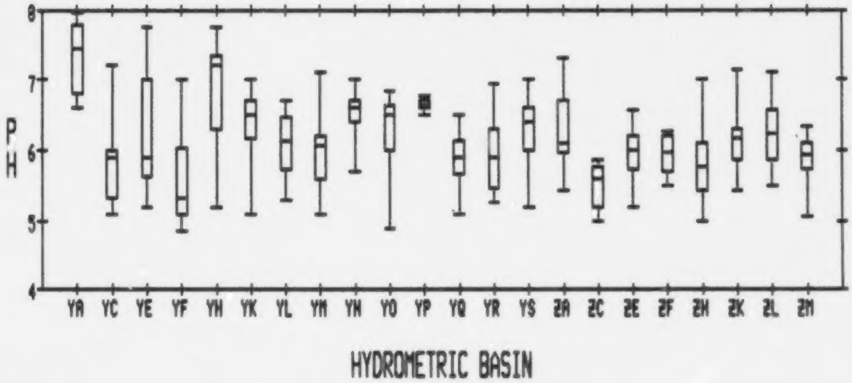
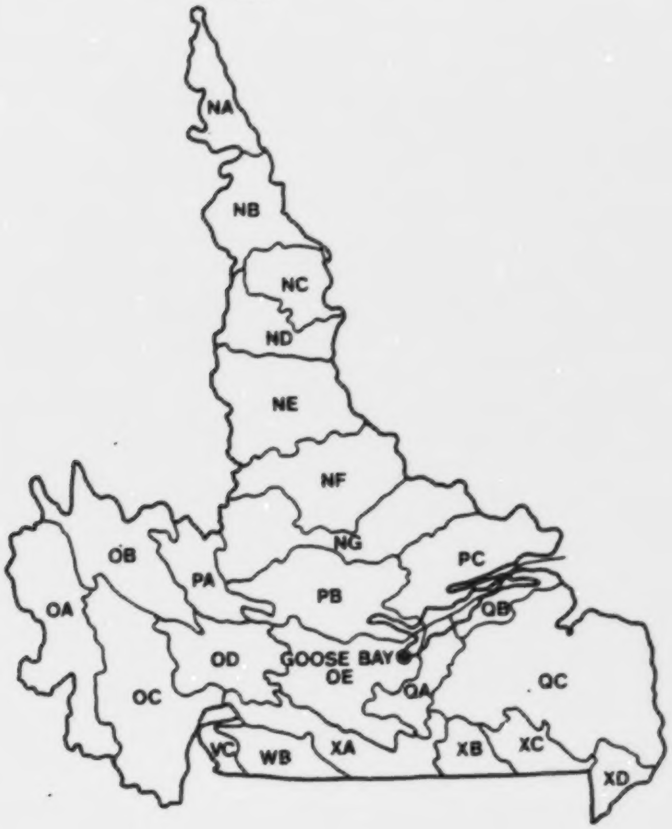

NEWFOUNDLAND
YA
YB
YC
YD
YE
YF
YG
YM
YH
YL
YP
CORNER BROOK
YJ
YK
YO
YQ
YR
YN
YS
ZJ
ZA
ZC
ZD
ZE
ZF
ZH
ZB
ZL
ST. JOHN'S
ZK
ZM
ZG
ZN

FIGURE 61 : BOXPLOT OF PH FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.

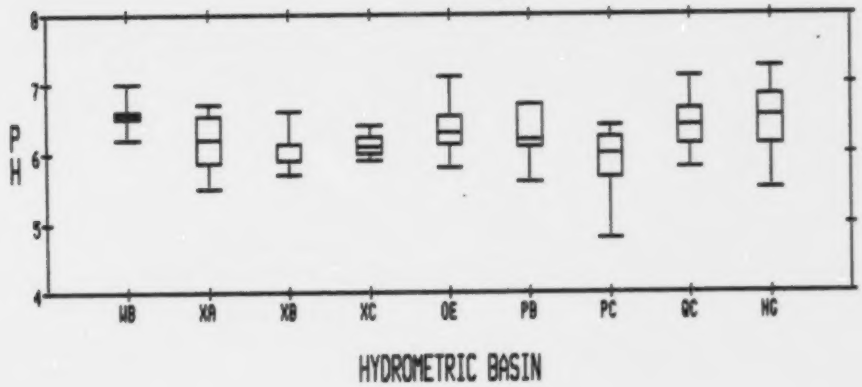




LABRADOR

NA
NB
NC
ND
NE
NF
NG
PC
OB
PA
PB
QB
OA
OD
GOOSE BAY
OE
QA
QC
OC
VC
WB
XA
XB
XC
XD

FIGURE 62 :BOXPLOT OF PH FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS.



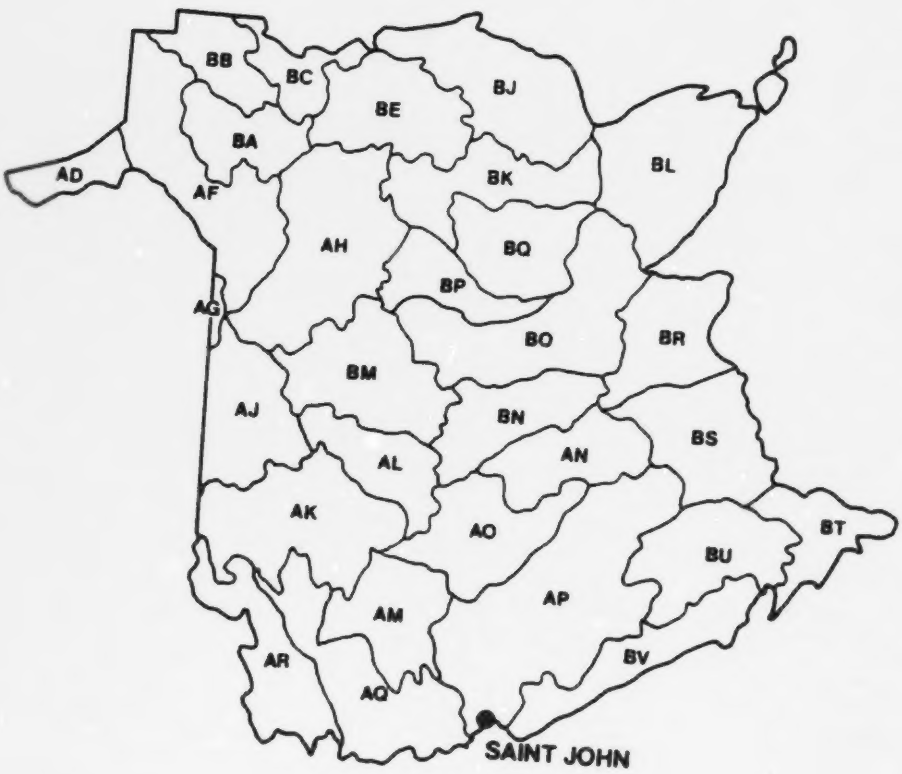
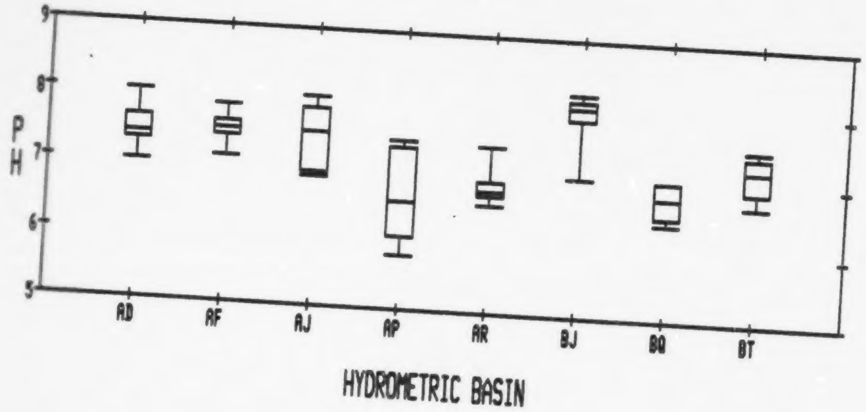

NEW BRUNSWICK
BB
BC
BE
BJ
BA
AD
AF
BK
BL
AH
BQ
BP
AG
BO
BR
BM
AJ
BN
AN
BS
AL
AK
AO
BT
BU
AP
AM
AR
BV
AQ
SAINT JOHN

FIGURE 63 :BOXPLOT OF PH FOR RIVERS IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS.



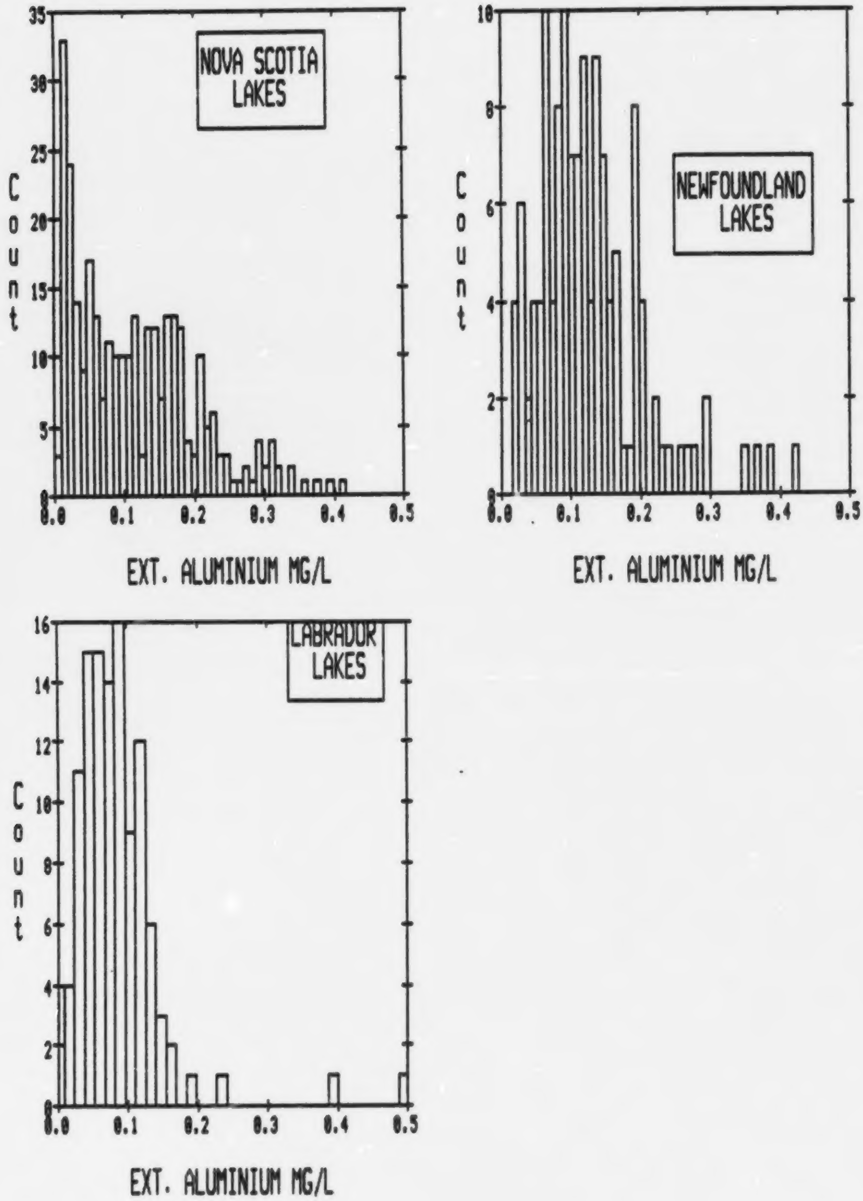


FIGURE 64:HISTOGRAMS OF EXTRACTABLE ALUMINIUM CONCENTRATIONS FOR LAKES IN THE ATLANTIC PROVINCES.

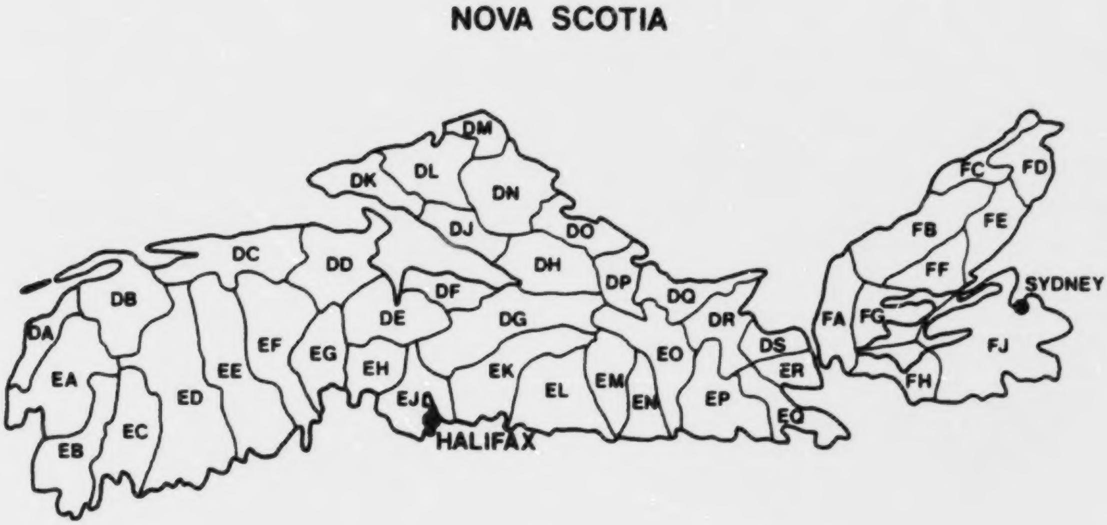
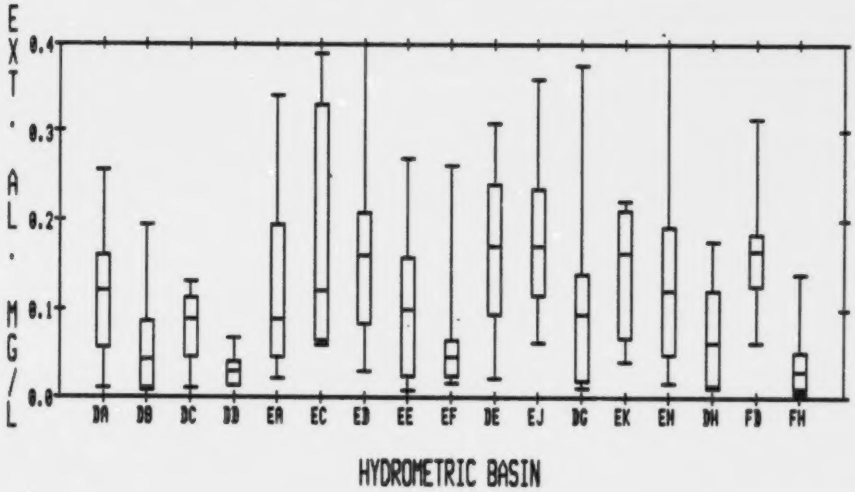

NOVA SCOTIA
DM
DL
DK
DN
DJ
DO
DC
DD
DH
DB
DF
DP
DQ
DA
DE
DG
DR
EA
EF
EG
EH
EK
EO
DS
EE
ED
EJ
EL
EM
EN
EP
ER
EB
EC
HALIFAX
EQ
FC
FD
FE
FB
FF
FA
FG
FJ
FH
SYDNEY

FIGURE 65 :BOXPLOT OF EXTRACTABLE ALUMINIUM CONCENTRATIONS FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.



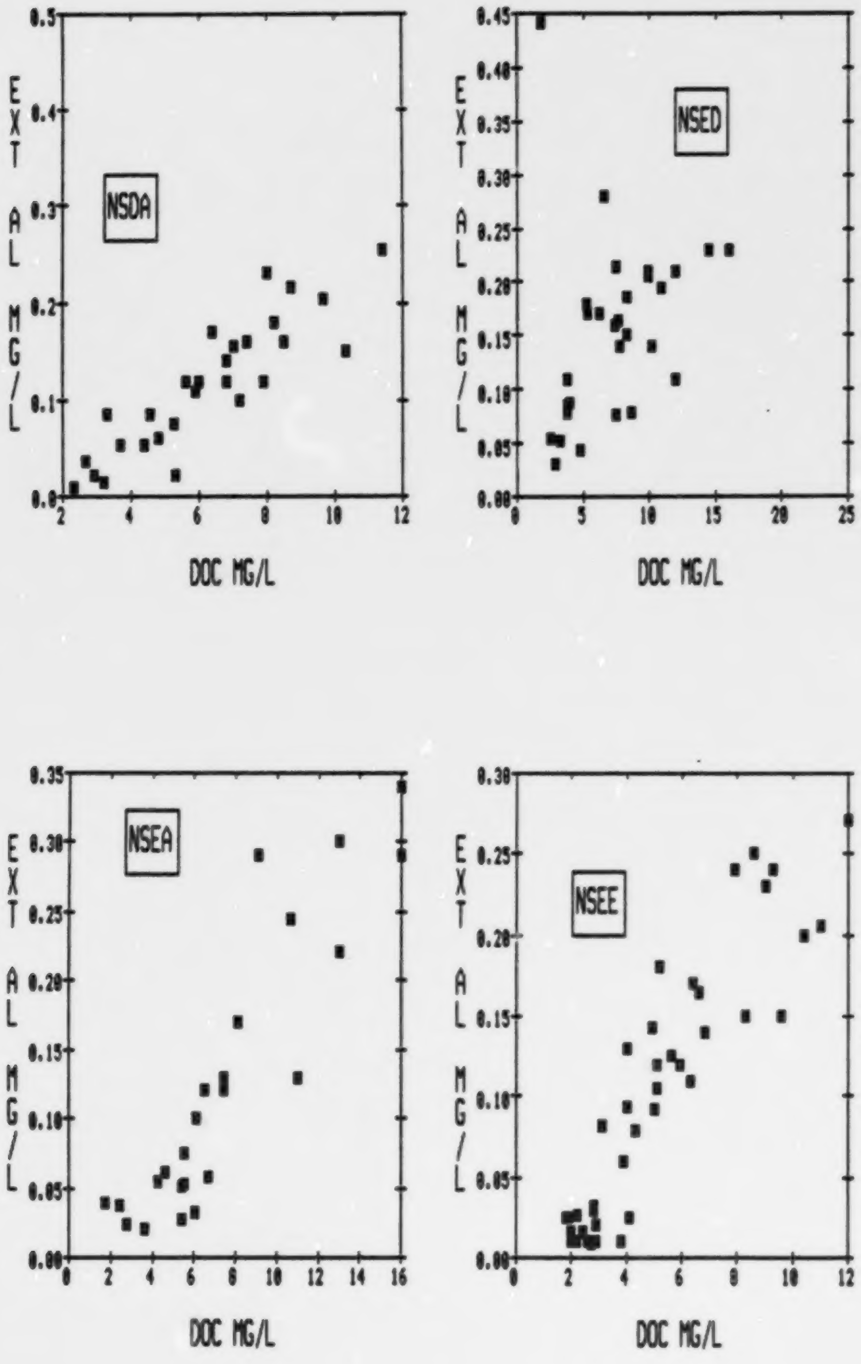


FIGURE 66:RELATIONSHIP BETWEEN EXTRACTABLE ALUMINIUM AND DISSOLVED ORGANIC CARBON CONCENTRATION FOR FOUR NOVA SCOTIA HYDROMETRIC BASINS

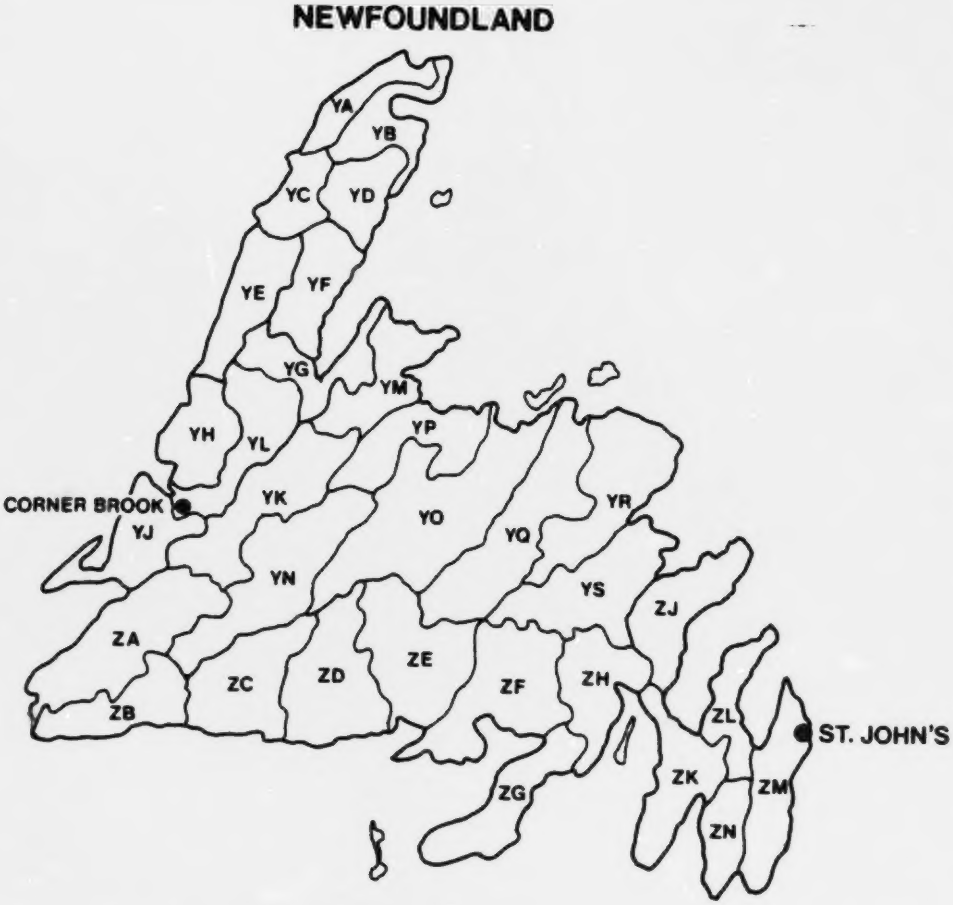
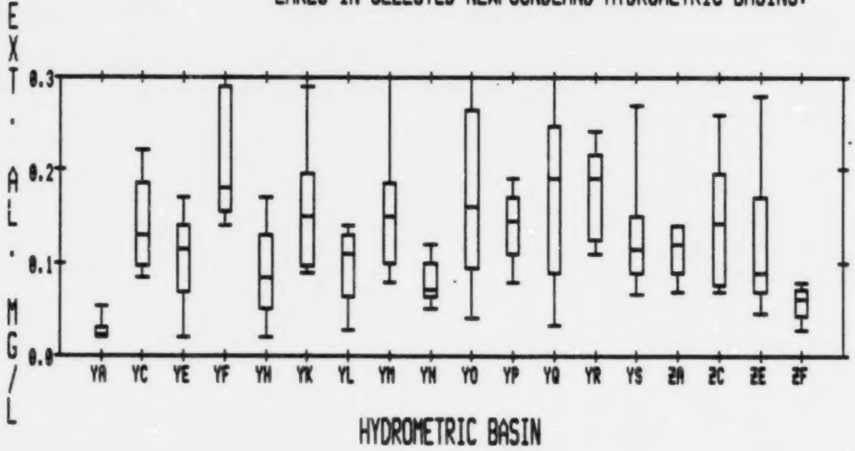
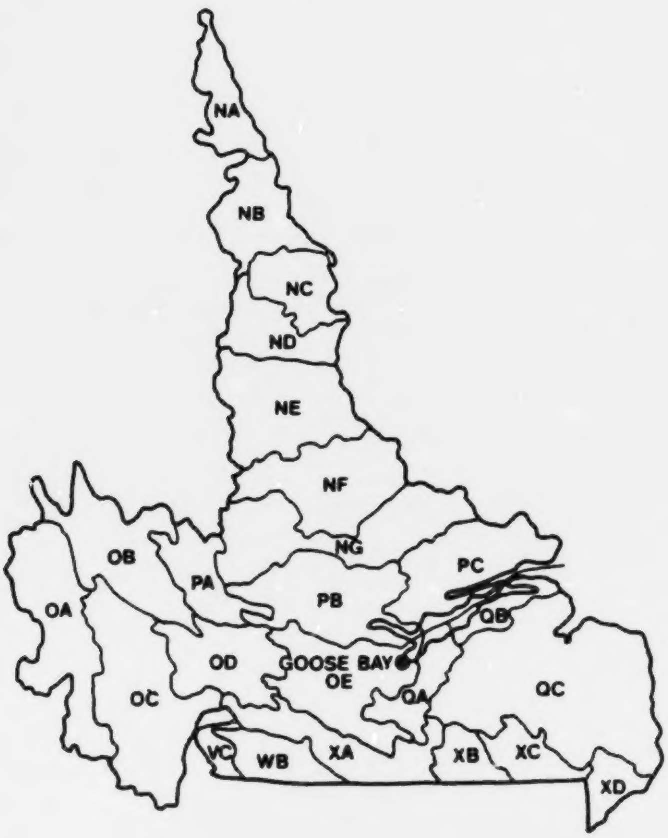

NEWFOUNDLAND
YA
YB
YC
YD
YE
YF
YG
YM
YH
YL
YP
CORNER BROOK
YK
YJ
YO
YQ
YR
YN
YS
ZJ
ZA
ZE
ZC
ZD
ZF
ZH
ZB
ZL
ST. JOHN'S
ZK
ZM
ZG
ZN

FIGURE 67 :BOXPLOT OF EXTRACTABLE ALUMINIUM CONCENTRATION FOR LAKES IN SELECTED NEWFOUNDLAND HYDROMETRIC BASINS.



LABRADOR


NA
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GOOSE BAY
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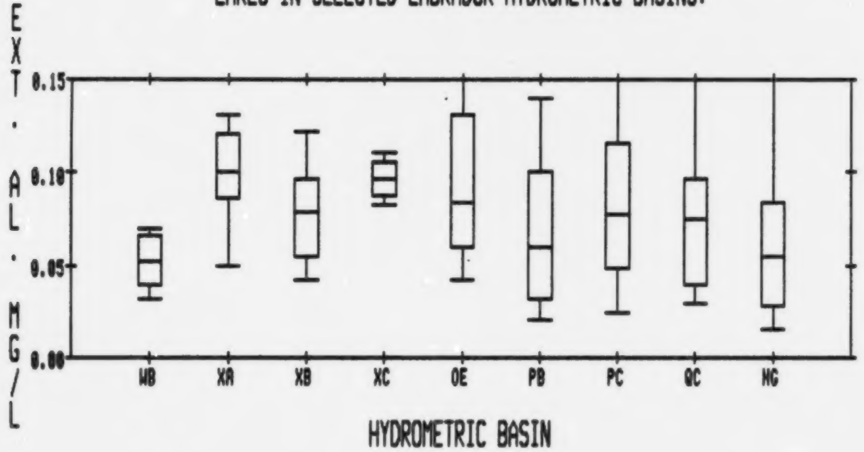
VC
WB
XA
XB
XC
XD

FIGURE :BOXPLOT OF EXTRACTABLE ALUMINIUM CONCENTRATION FOR LAKES IN SELECTED LABRADOR HYDROMETRIC BASINS.



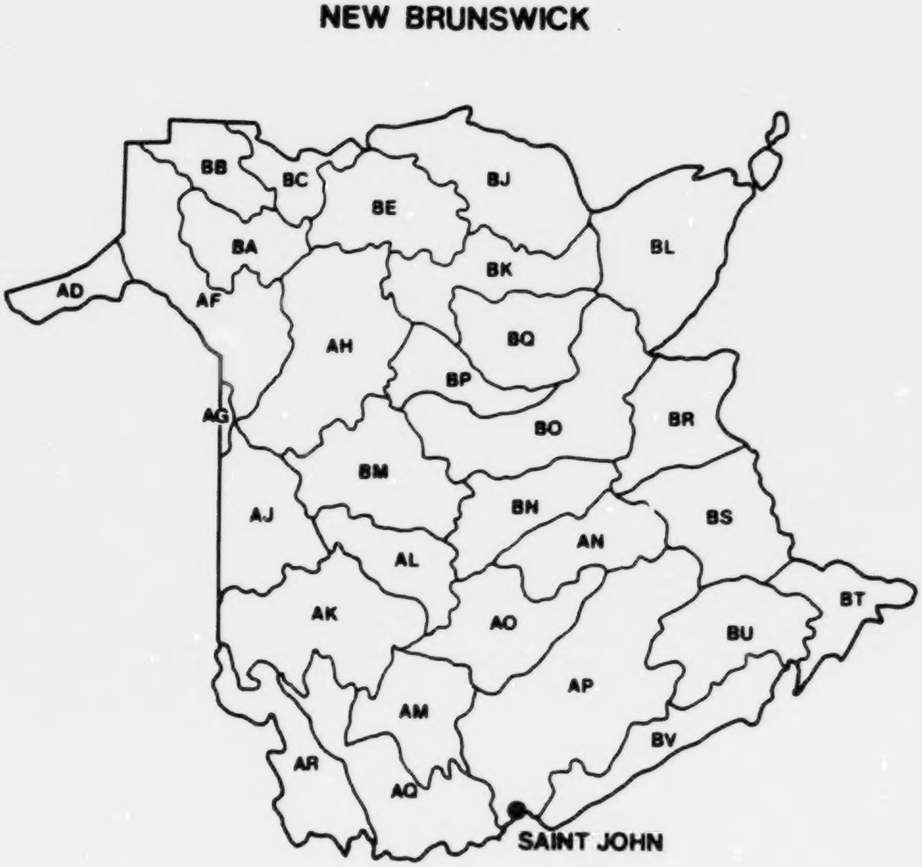

NEW BRUNSWICK
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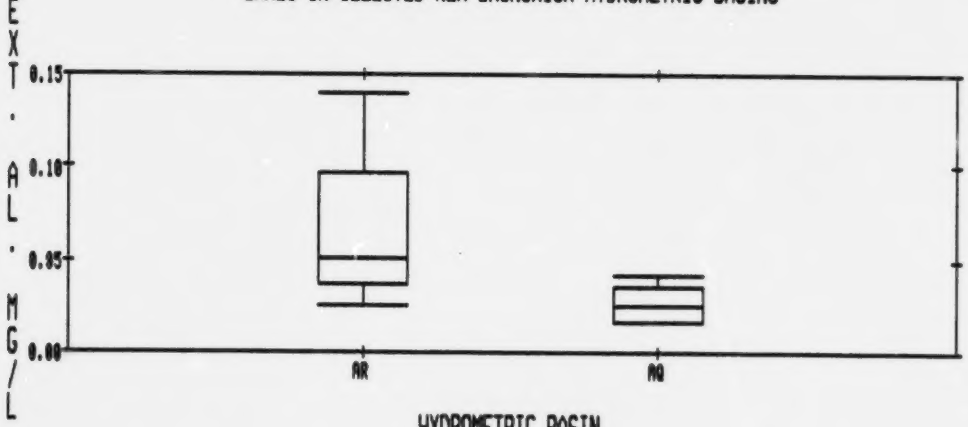
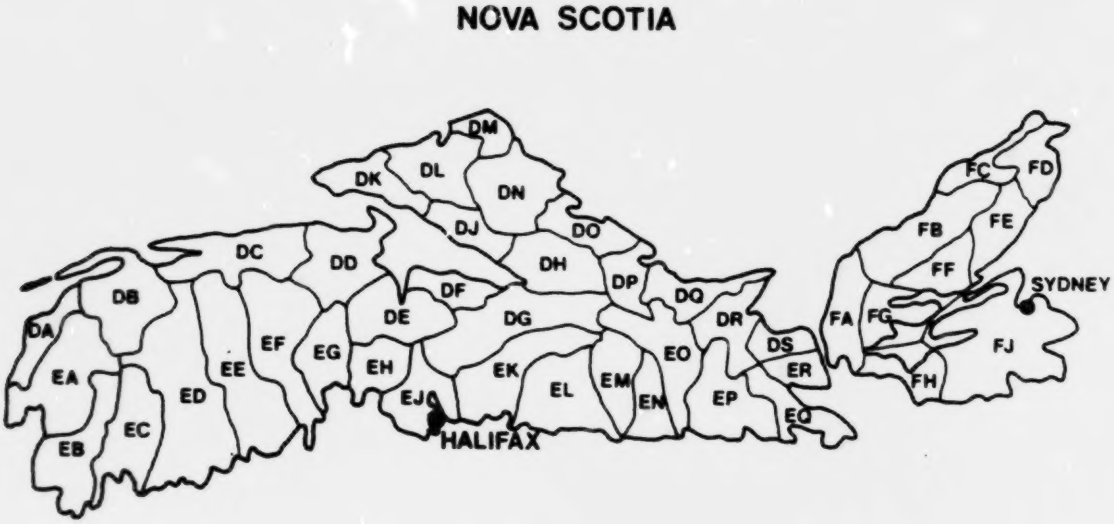
FIGURE 69 : BOXPLOT OF EXTRACTABLE ALUMINIUM CONCENTRATION FOR LAKES IN SELECTED NEW BRUNSWICK HYDROMETRIC BASINS




NOVA SCOTIA
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DC
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EO
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EH
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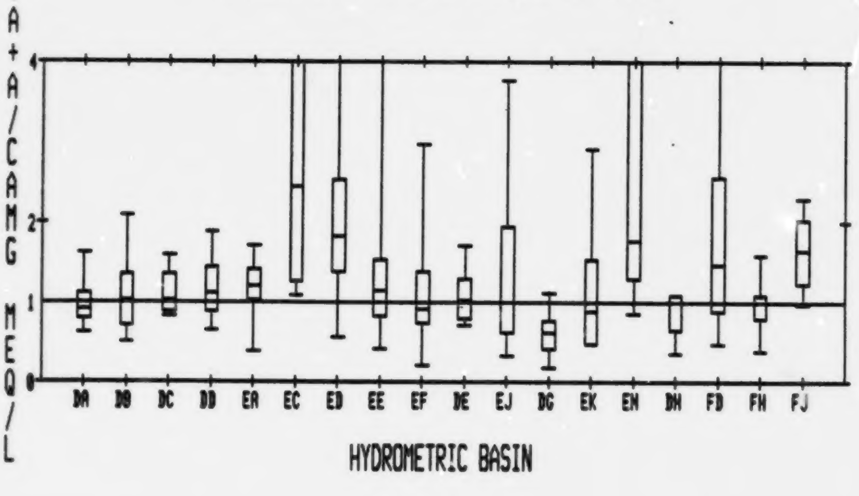
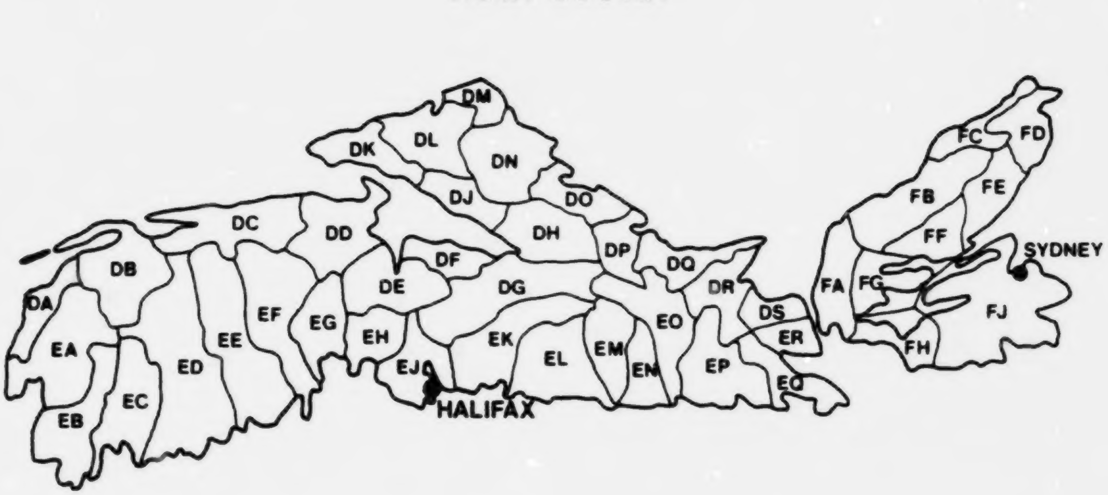
EL
EM
EN
EP
EE
ED
EJ
EQ
EC
EB
HALIFAX
FC
FD
FB
FE
FF
SYDNEY
FA
FG
FJ
FH

FIGURE :BOXPLOT OF THE ORGANIC ANION CORRECTED ALKALINITY TO EXCESS CALCIUM AND MAGNESIUM RATIO FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.




NOVA SCOTIA
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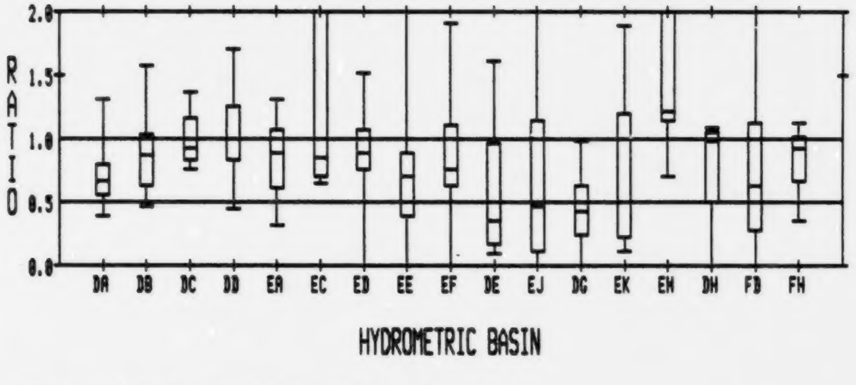
EH
EK
EM
EO
ER
ED
EJ
EL
EN
EP
EQ
EC
EB
HALIFAX
FC
FD
FB
FE
FF
SYDNEY
FA
FG
FJ
FH

FIGURE 71 :BOXPLOT OF ORGANIC ANION CORRECTED ALKALINITY TO EXCESS CALCIUM AND MAGNESIUM RATIO FOR LAKES IN SELECTED NOVA SCOTIA HYDROMETRIC BASINS.



RATIO = ALK + OA -(FE+AL)/CA*+MG* MEQ/L

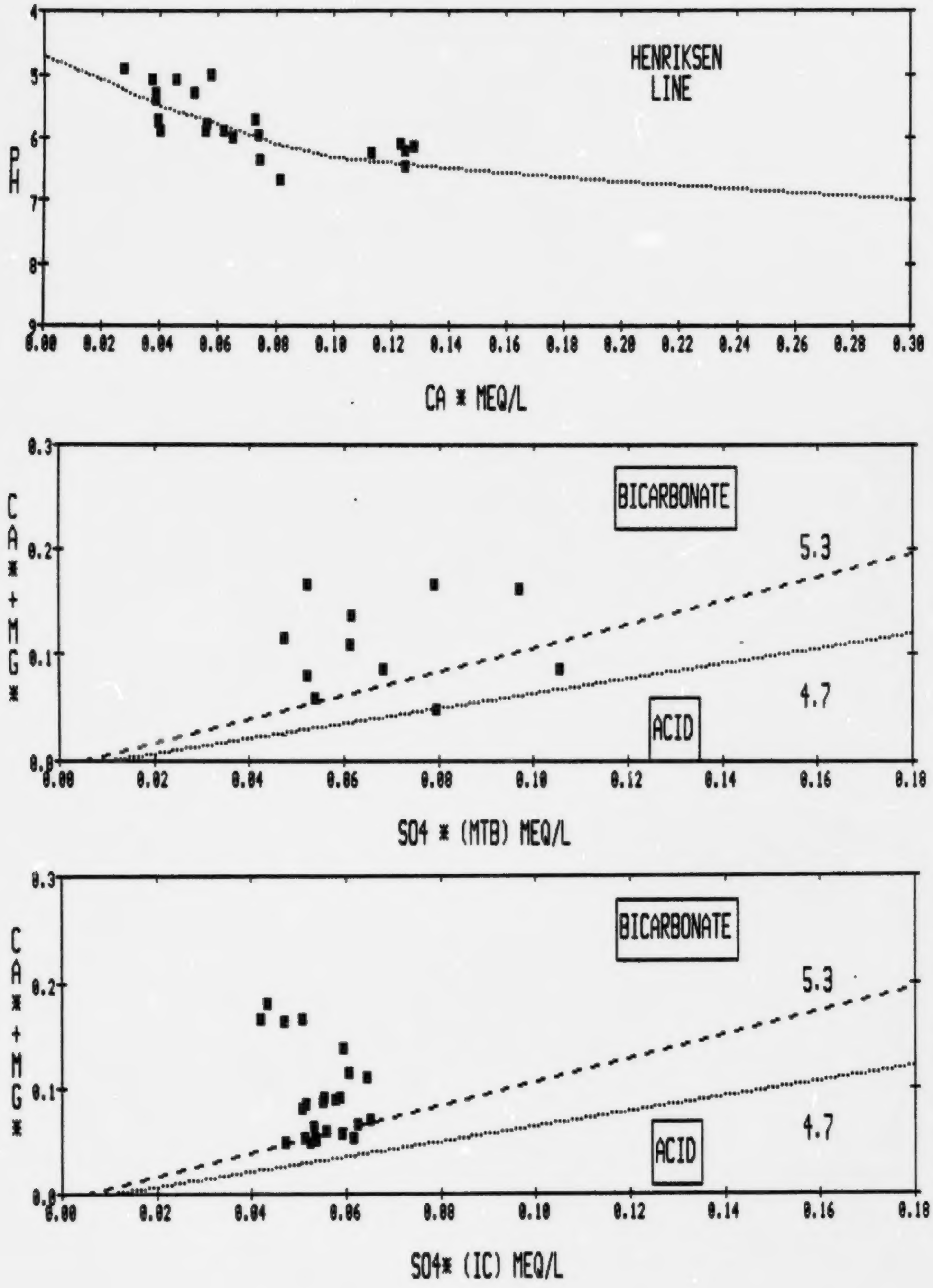


FIGURE 72(a,b,c):APPLICATION OF THE NOVA SCOTIA HYDROMETRIC BASIN 01EA DATA TO THE HENRIKSEN MODELS.

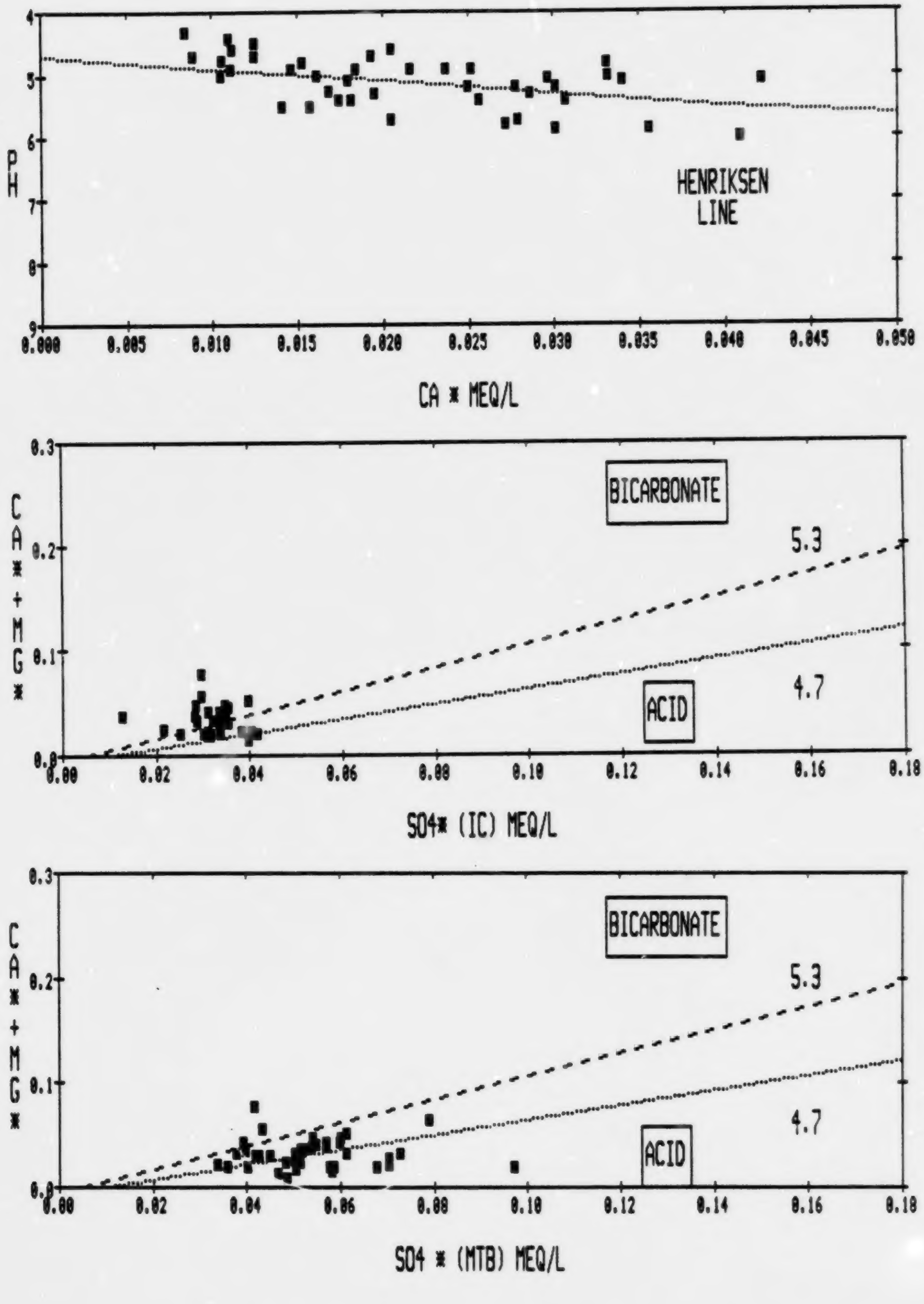


FIGURE 73(a,b,c):APPLICATION OF THE NOVA SCOTIA HYDROMETRIC BASIN 01ED DATA TO THE HENRIKSEN MODELS.

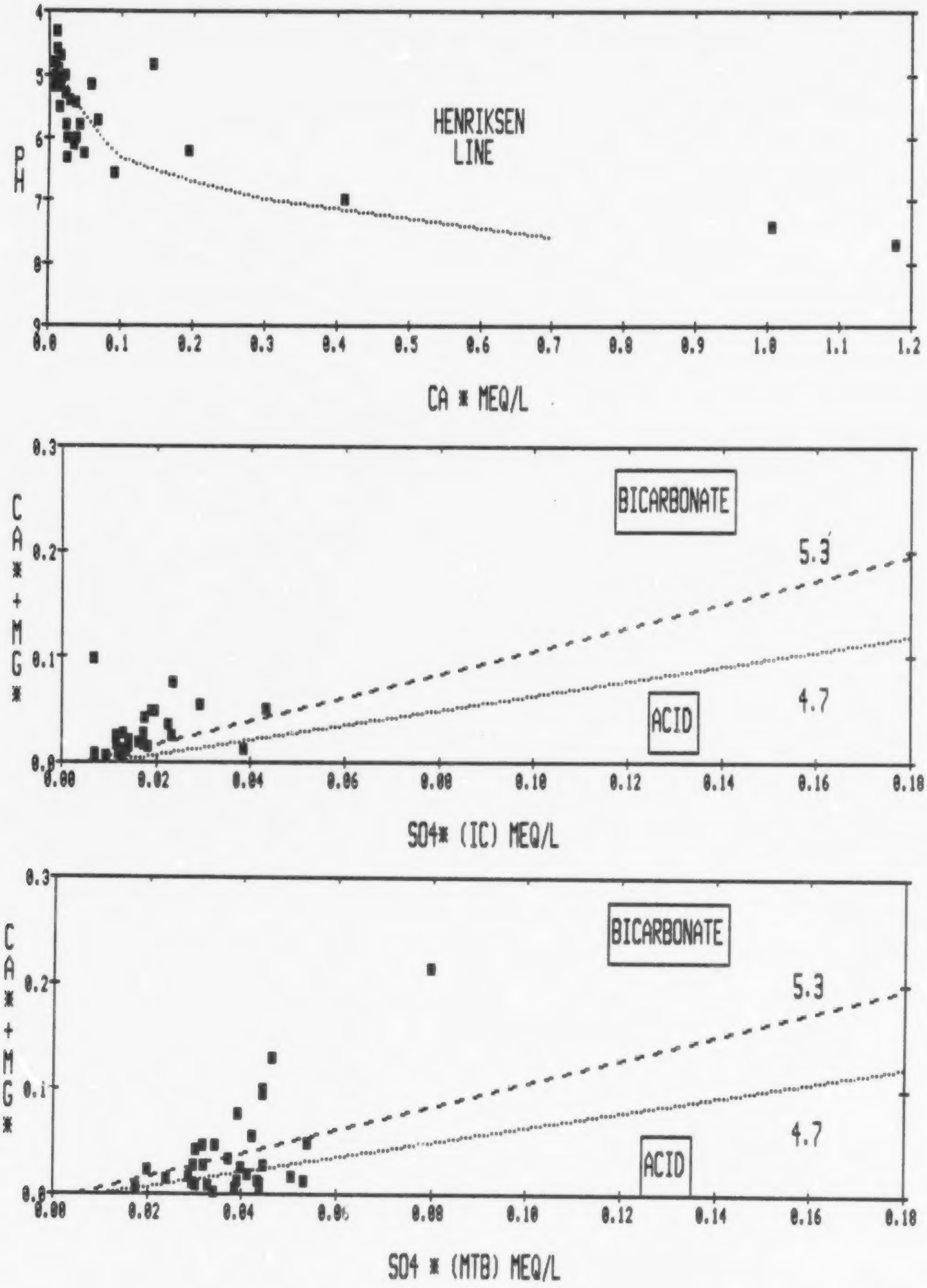


FIGURE 74(a,b,c):APPLICATION OF THE NOVA SCOTIA HYDROMETRIC BASIN 01FD DATA TO THE HENRIKSEN MODELS.

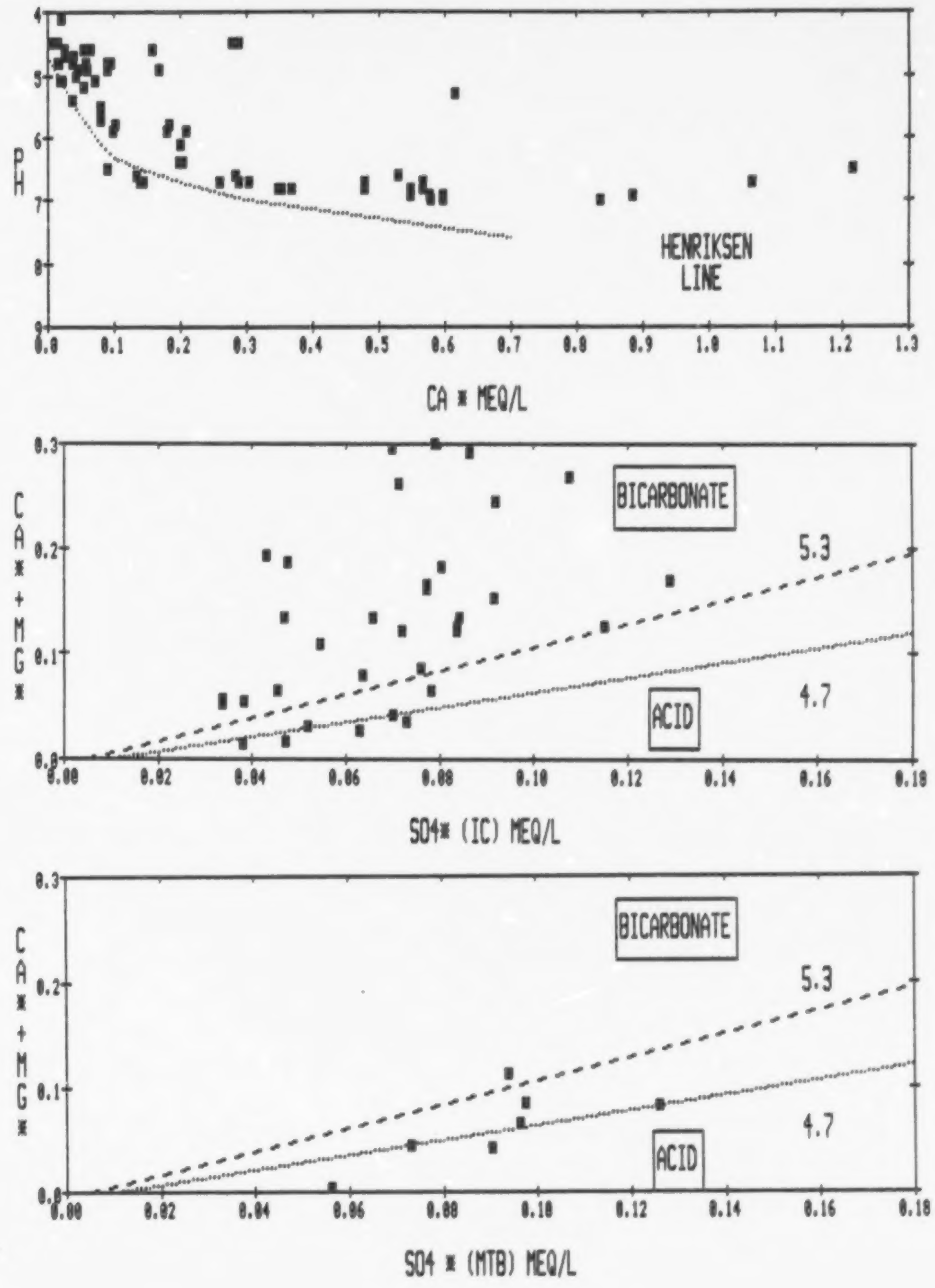


FIGURE 75(a,b,c):APPLICATION OF THE NOVA SCOTIA HYDROMETRIC BASIN 01EJ DATA TO THE HENRIKSEN MODELS.

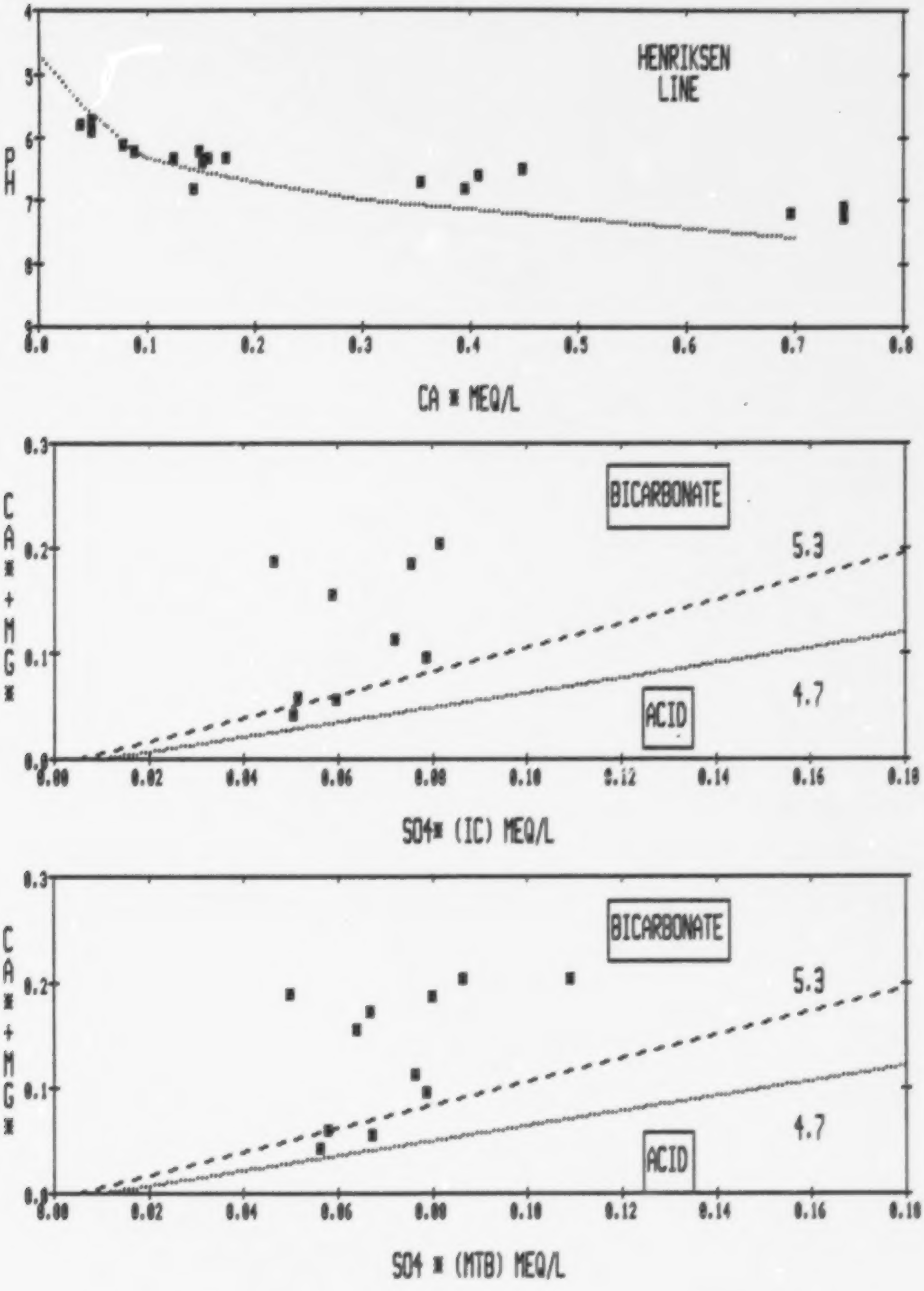


FIGURE 76(a,b,c):APPLICATION OF THE NEW BRUNSWICK LAKE DATA TO THE HENRIKSEN MODELS.

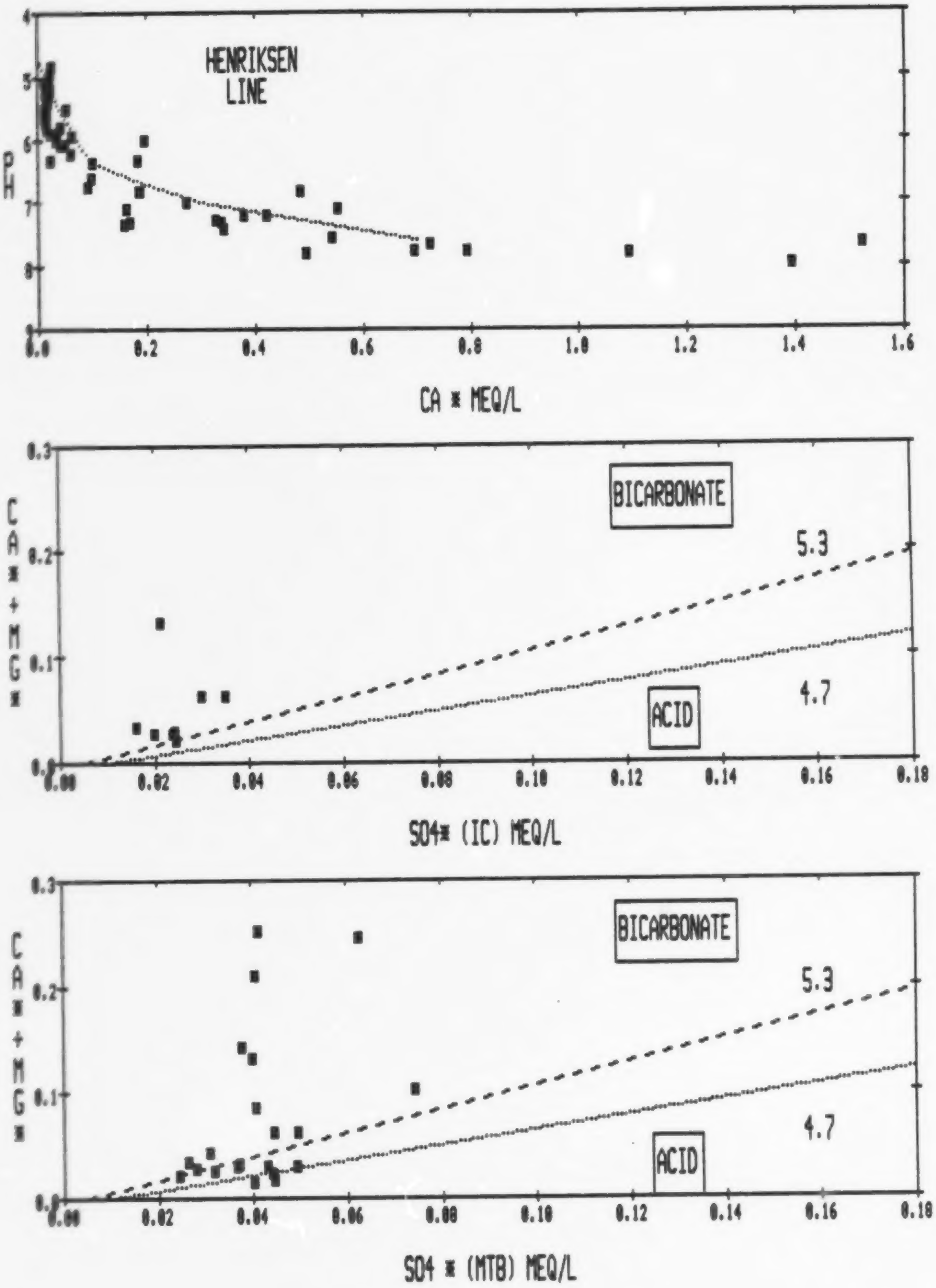


FIGURE 77(a,b,c):APPLICATION OF THE NEWFOUNDLAND GREAT NORTHERN PENINSULA HYDROMETRIC BASIN DATA TO THE HENRIKSEN MODELS.

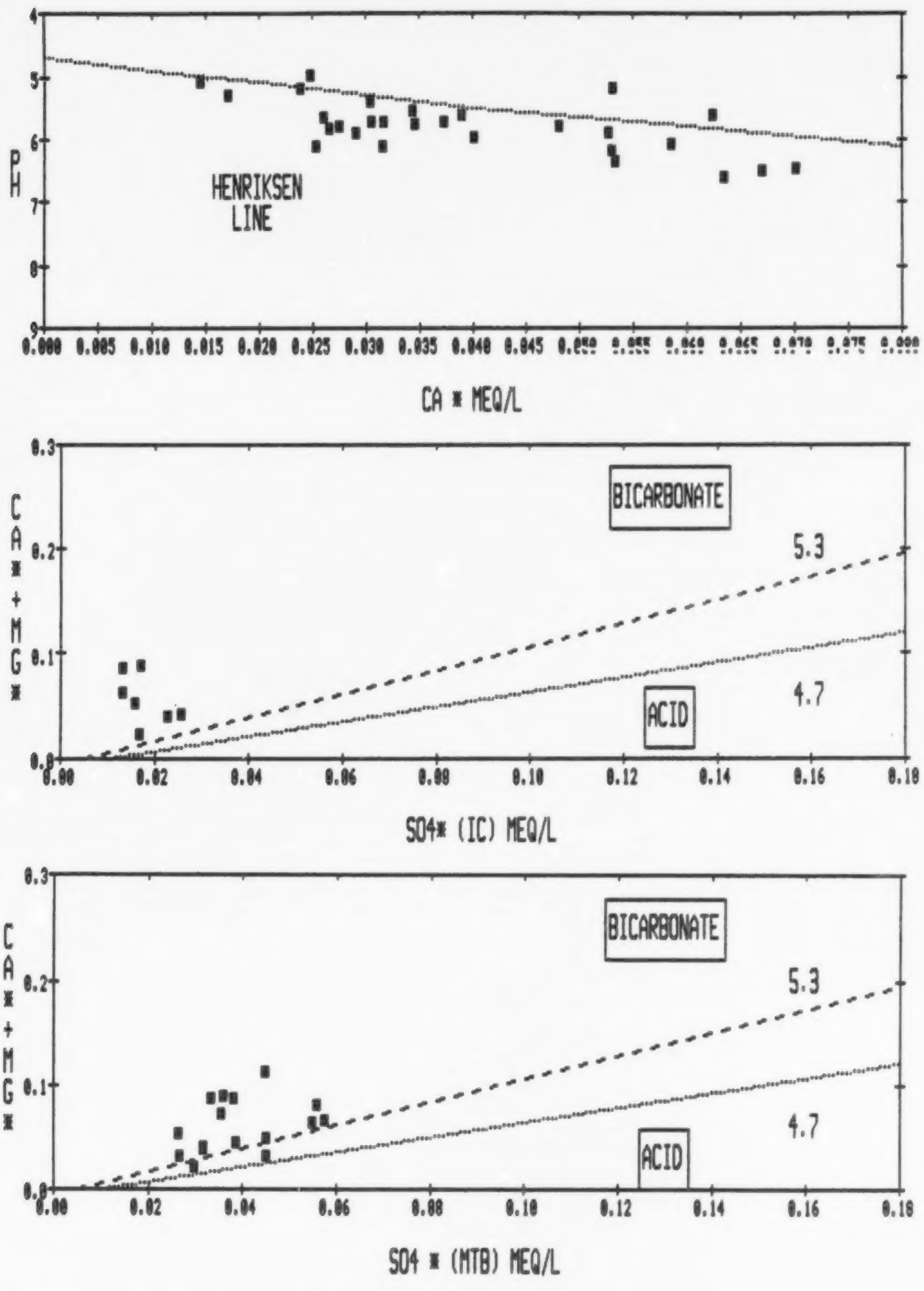


FIGURE 78(a,b,c):APPLICATION OF THE NEWFOUNDLAND SOUTH COAST HYDROMETRIC BASIN DATA TO THE HENRIKSEN MODELS.

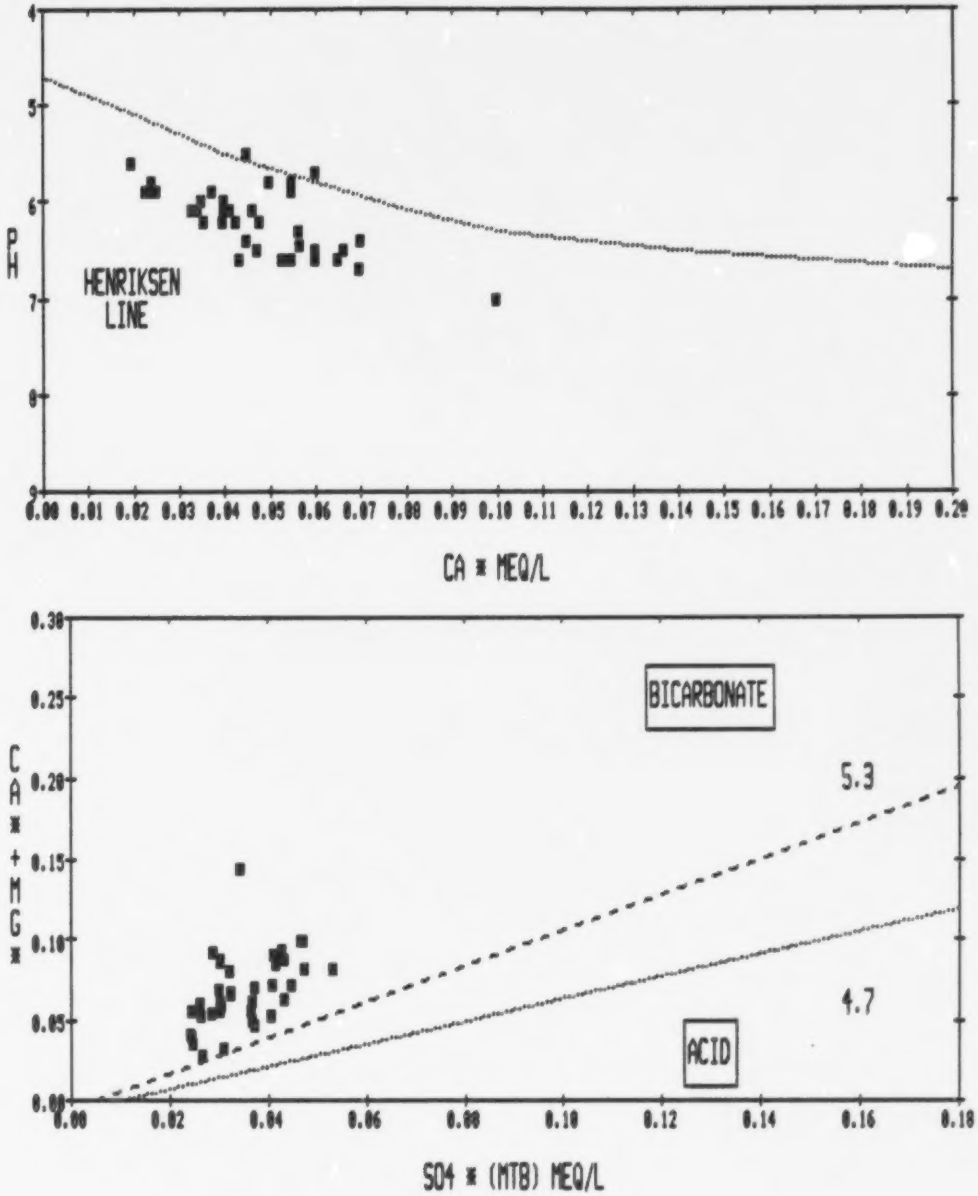


FIGURE 79(a,b):APPLICATION OF THE SOUTHERN LABRADOR HYDROMETRIC BASIN DATA TO THE HENRIKSEN MODELS.

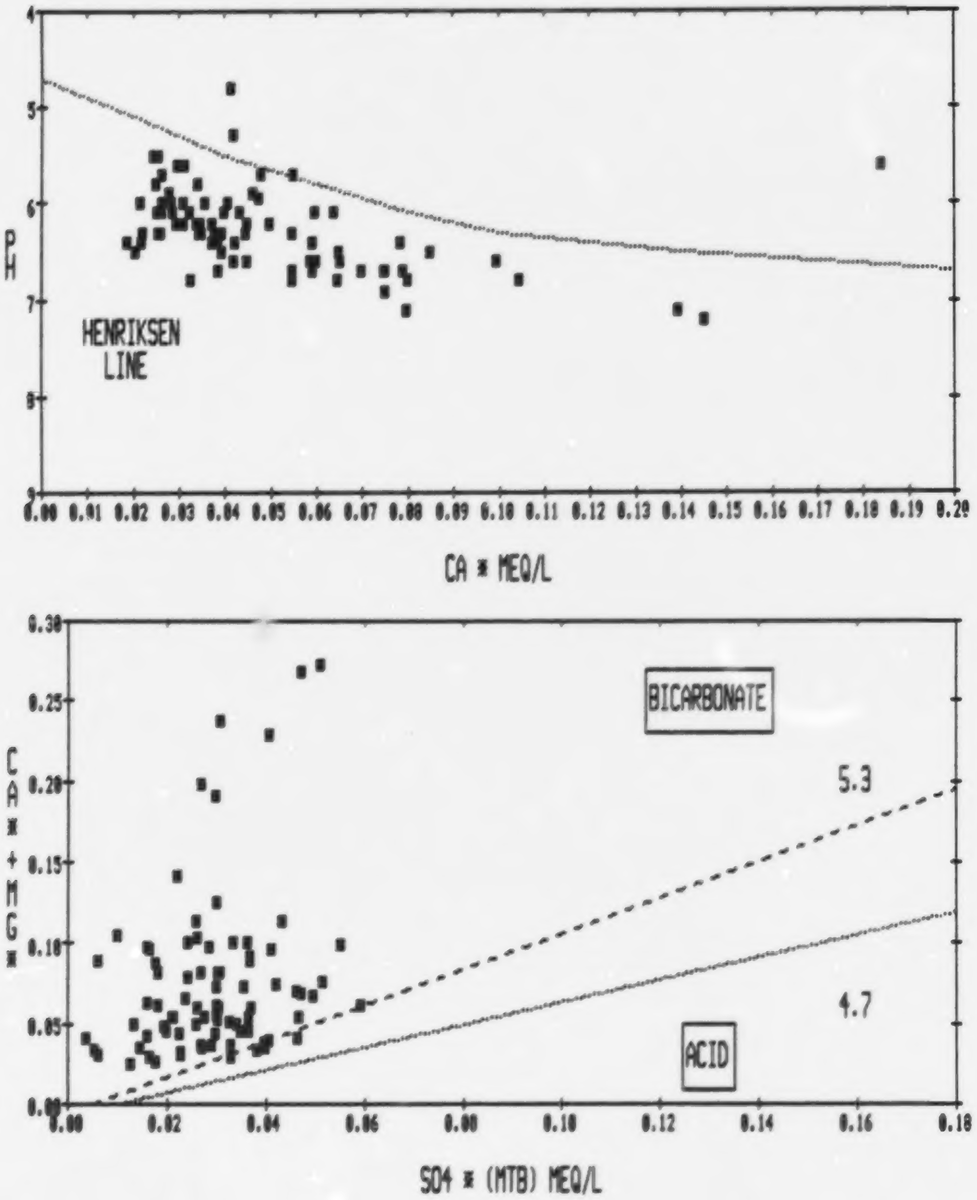


FIGURE 80(a,b):APPLICATION OF THE CENTRAL AND NORTHERN LABRADOR HYDROMETRIC BASIN DATA TO THE HENRIKSEN MODELS.

FIGURE 81: RUNNING BOXPLOTS OF pH FOR SELECTED NOVA SCOTIA AND NEWFOUNDLAND RIVERS FROM 1965 TO 1985. THE LINES INDICATE THE UPPER AND LOWER QUARTILES AND THE MEDIANS WHILE THE POINTS INDICATE THE EXTREME VALUES.

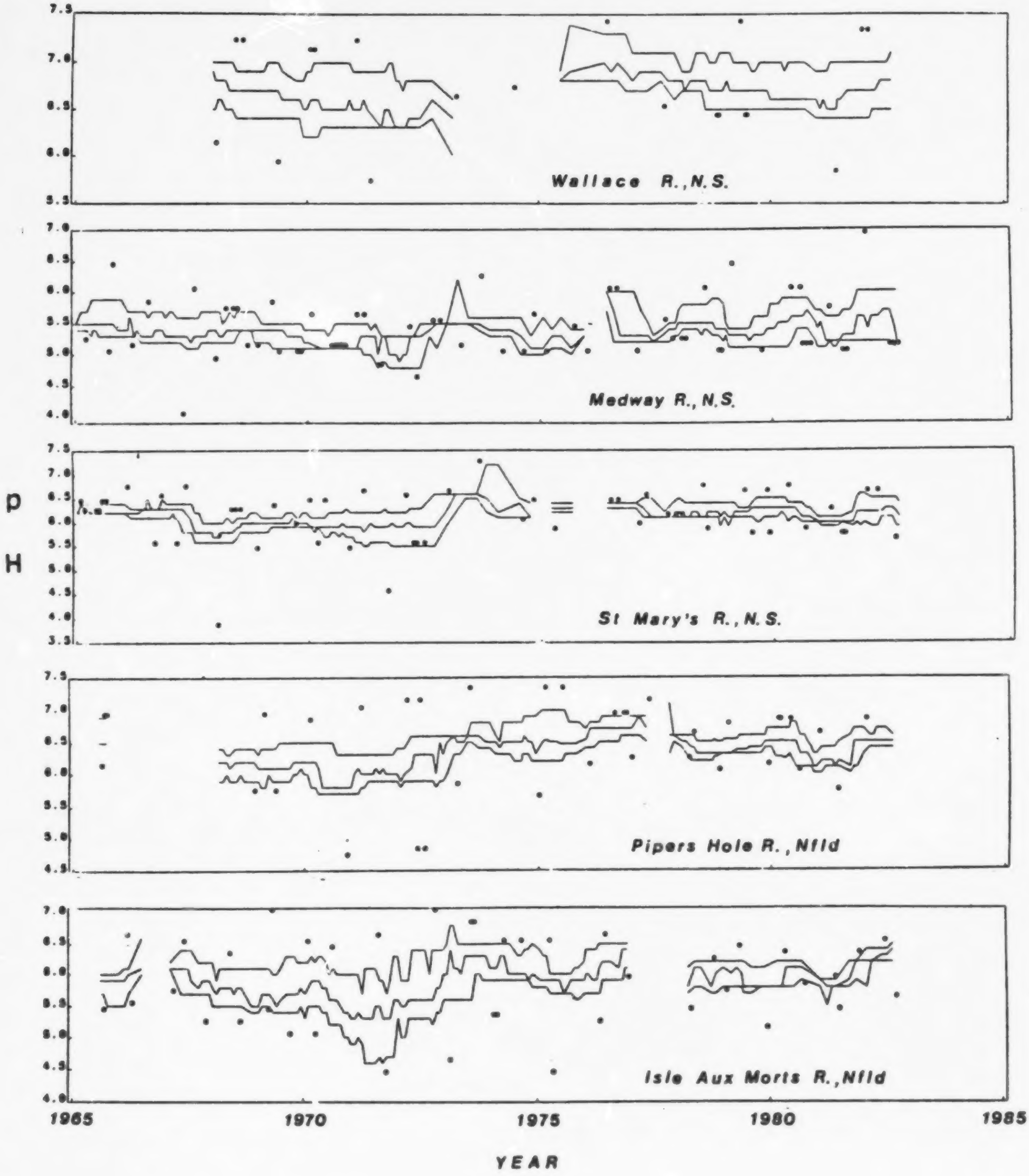


FIGURE 82:PLOTS OF THE FITTED YEARLY pH VALUES FROM THE ANOVA MODELS FOR THE NOVA SCOTIA AND NEWFOUNDLAND RIVERS.

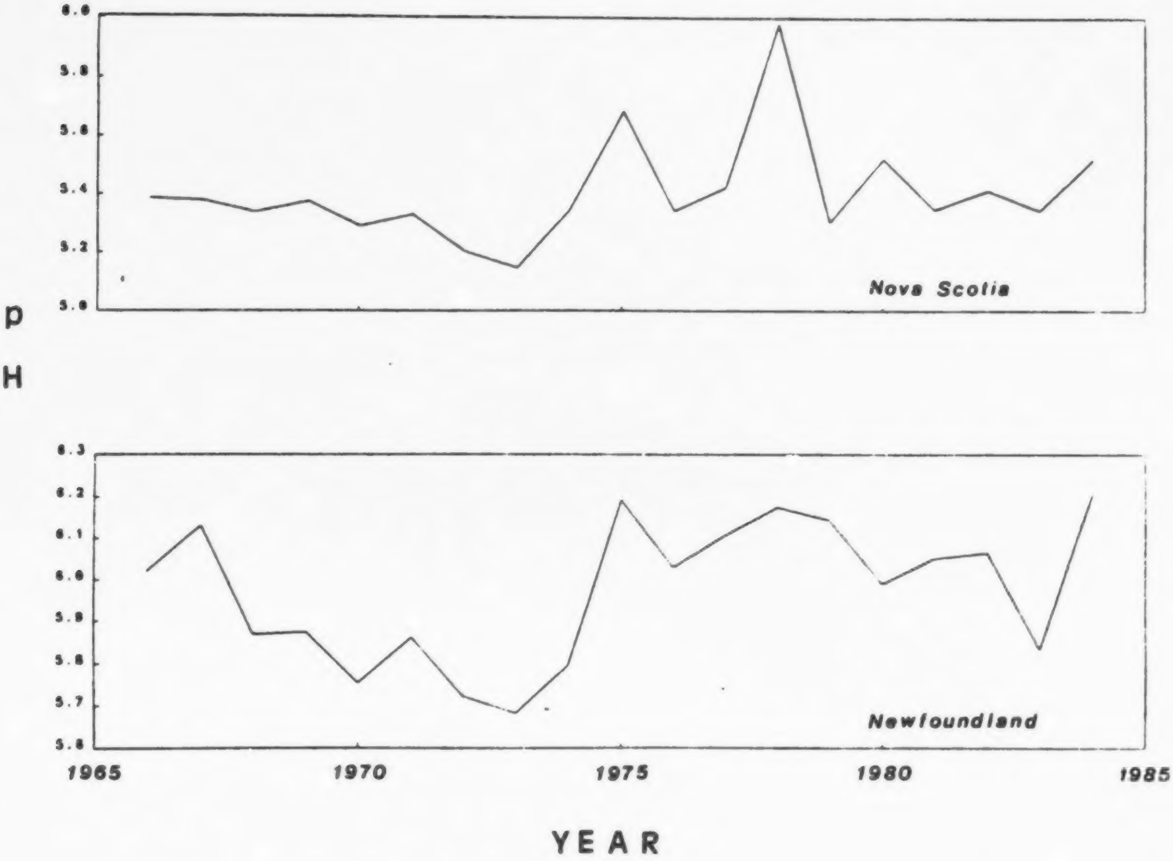
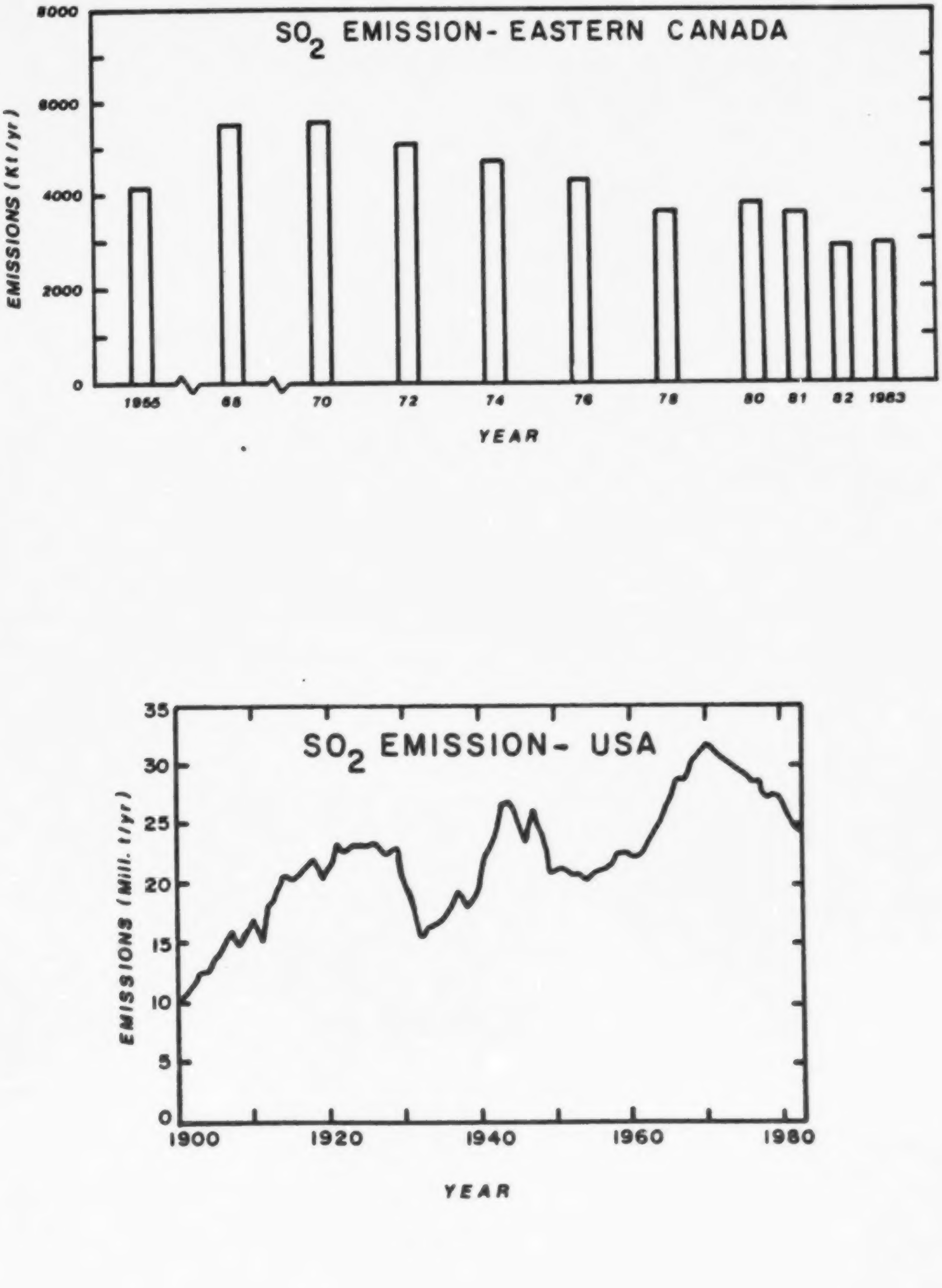


Figure 83. Temporal Changes in SO_2 Emissions in Eastern Canada and USA (from Martin and Brydges, 1986)



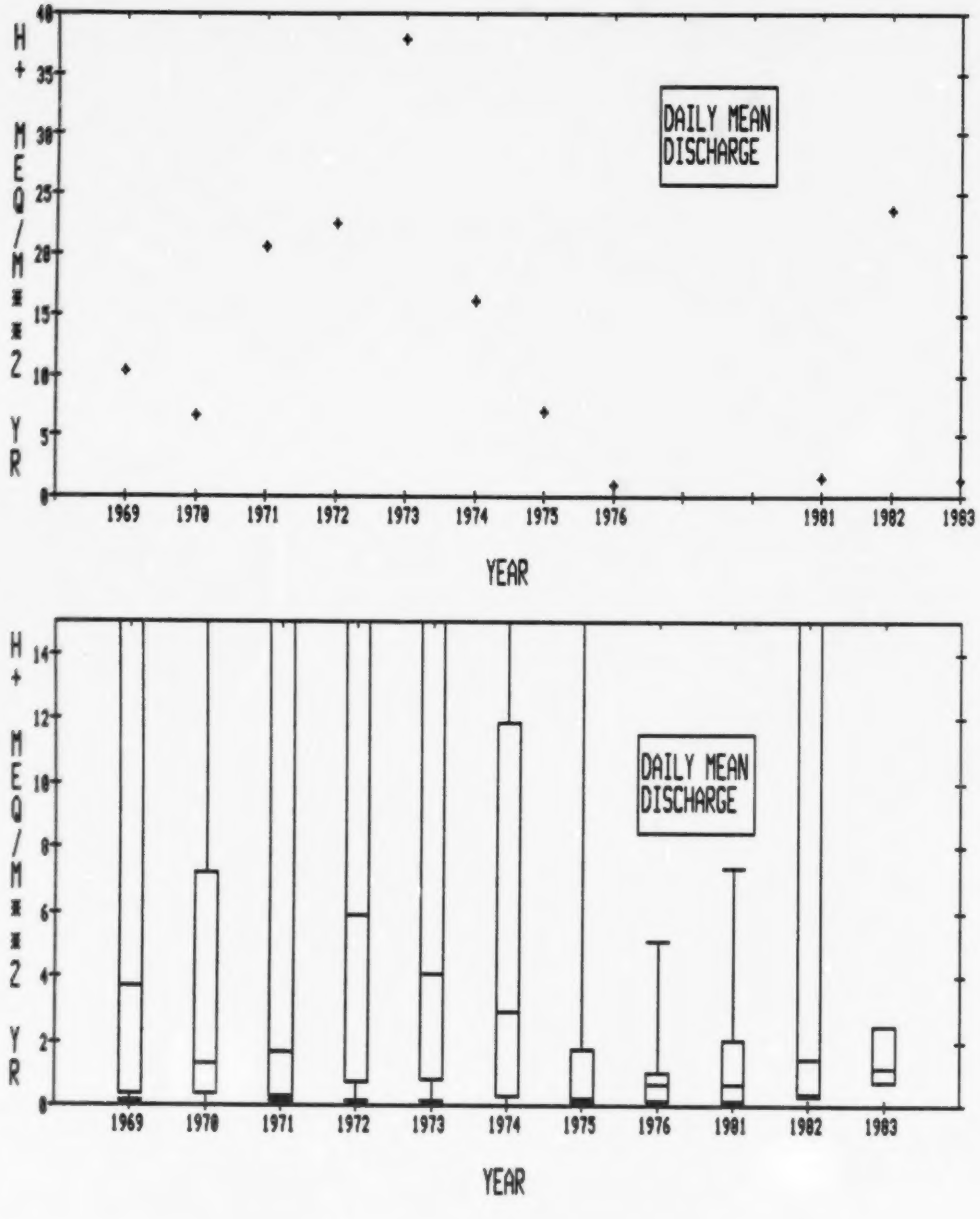


FIGURE 84a: TEMPORAL CHANGES IN HYDROGEN ION EXPORT FOR THE ISLE AUX MORTS RIVER CALCULATED WITH DAILY MEAN DISCHARGE VALUES.

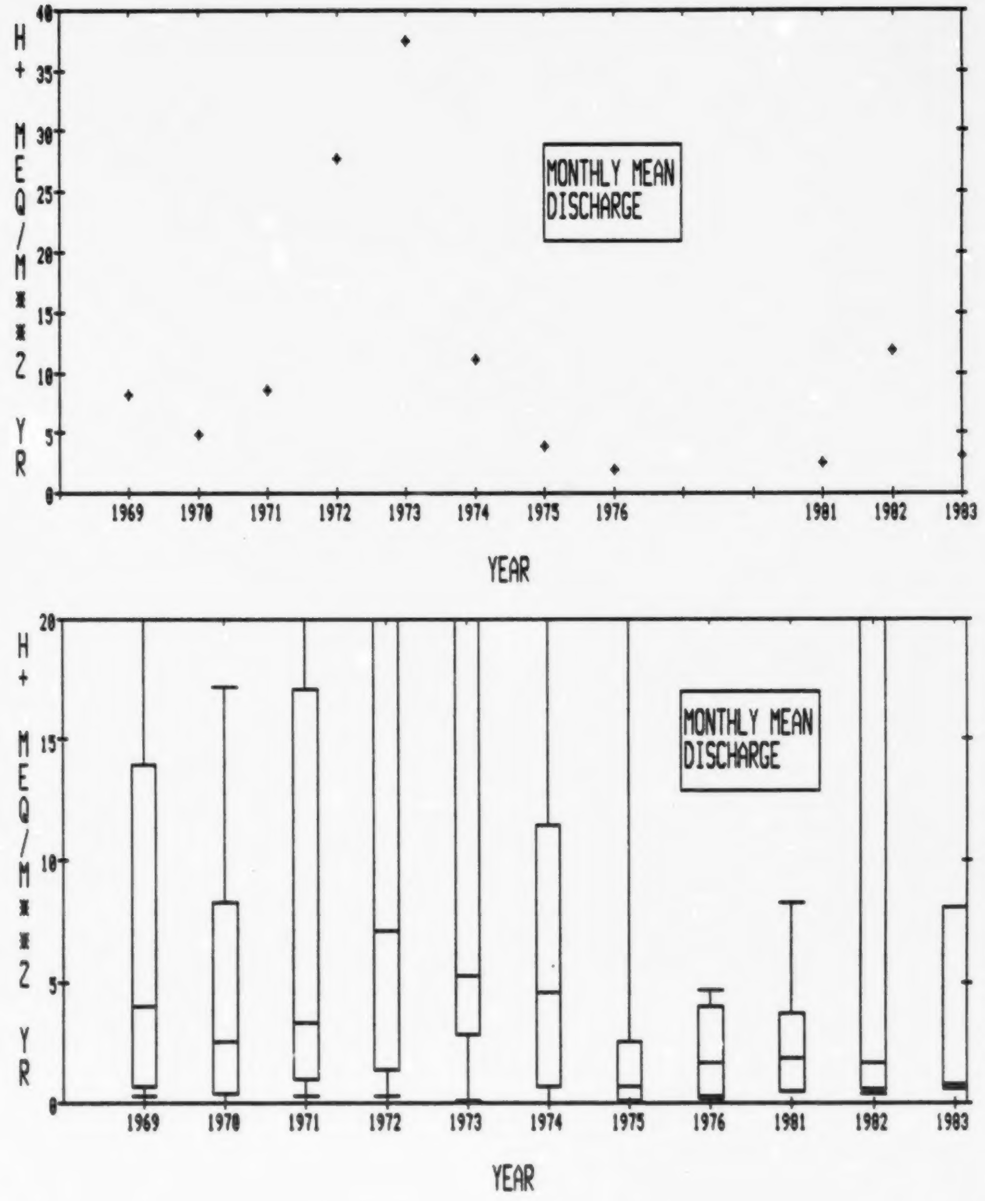


FIGURE 84b: TEMPORAL CHANGES IN HYDROGEN ION EXPORT FOR THE ISLE AUX MORTS RIVER CALCULATED WITH MONTHLY MEAN DISCHARGE VALUES.

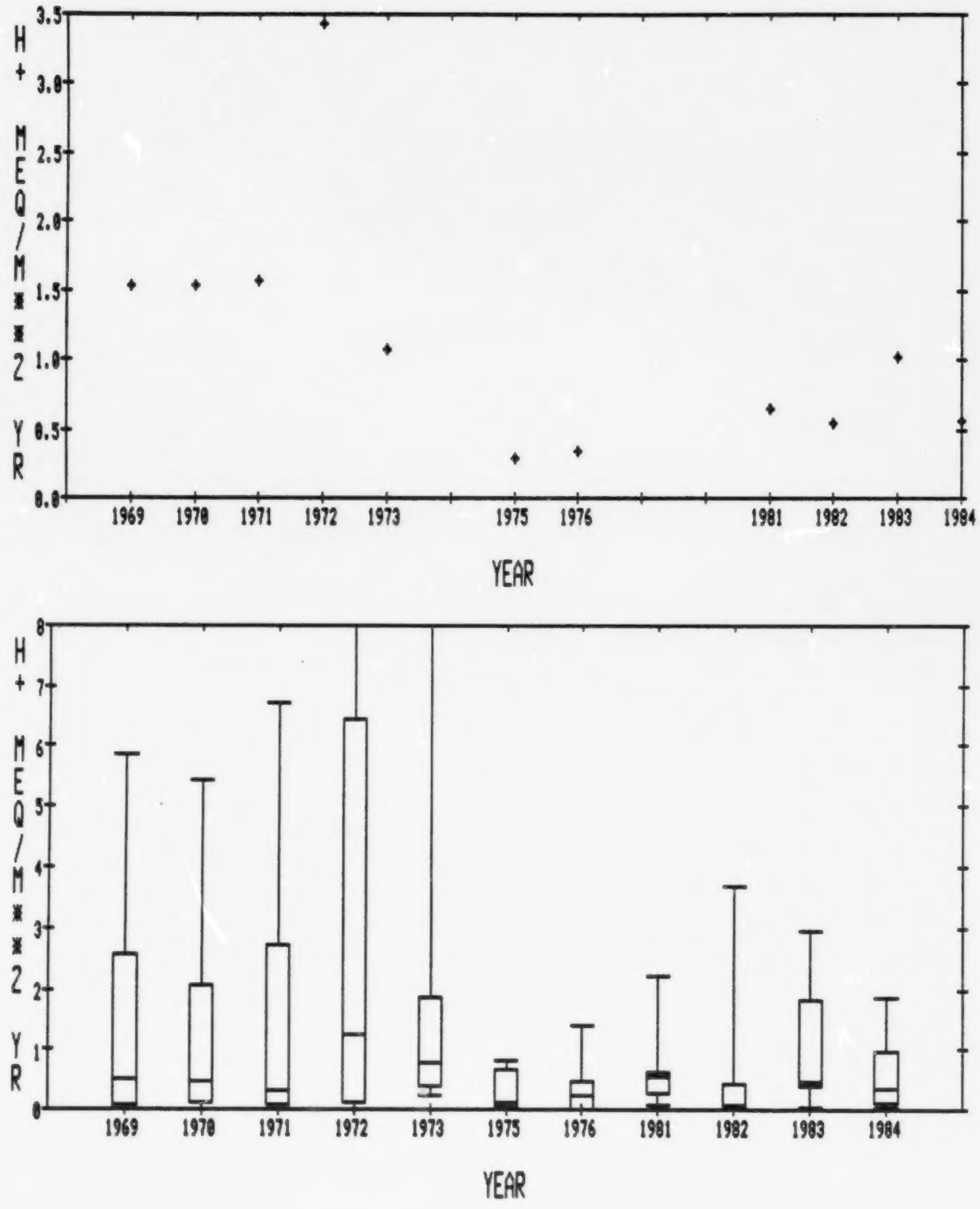


FIGURE 85a: TEMPORAL CHANGES IN HYDROGEN ION EXPORT FOR THE PIPER'S HOLE RIVER CALCULATED WITH DAILY MEAN DISCHARGE VALUES.

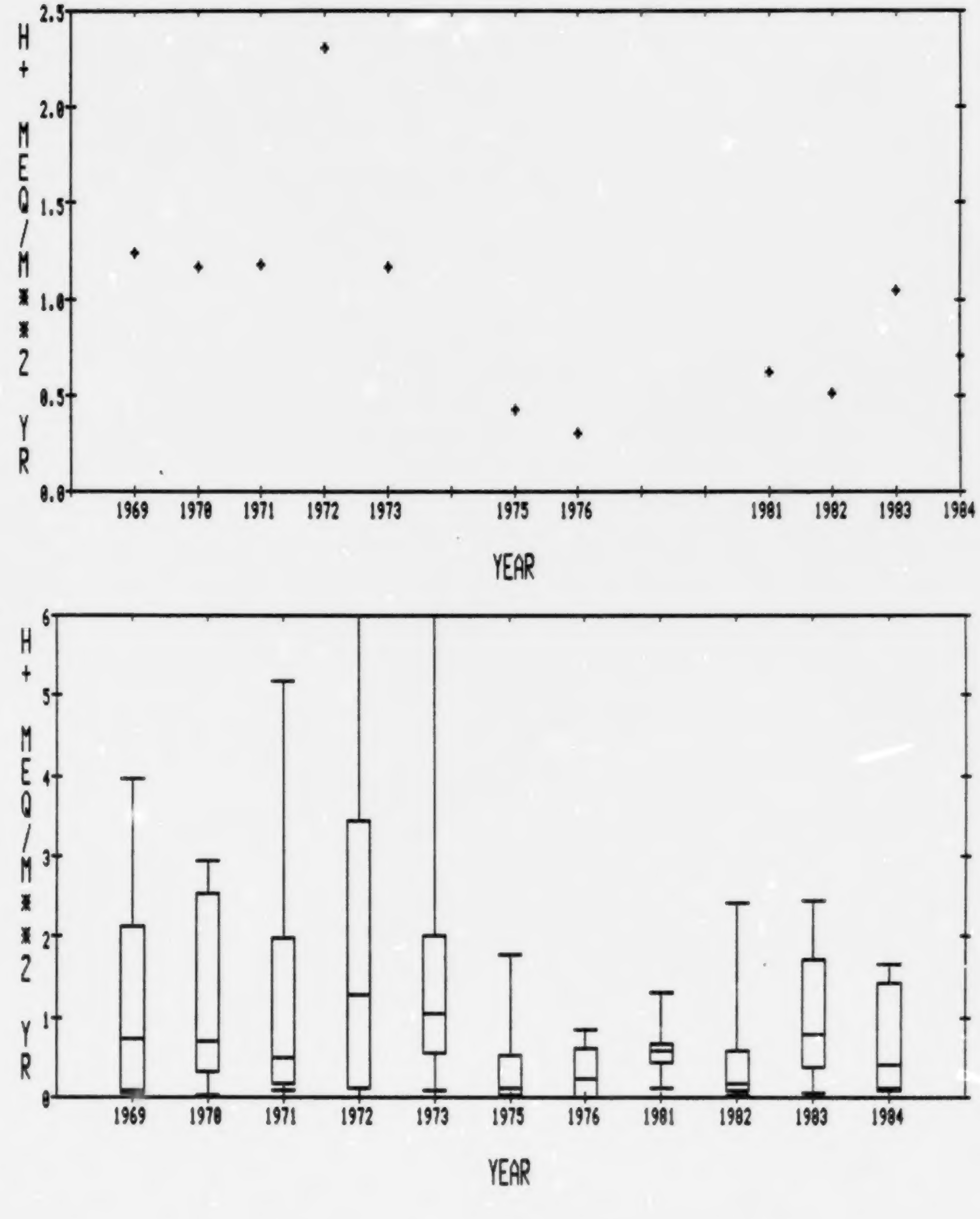


FIGURE 85b: TEMPORAL CHANGES IN HYDROGEN ION EXPORT FOR THE PIPER'S HOLE RIVER CALCULATED WITH MONTHLY MEAN DISCHARGE VALUES.

FIGURE 86a : TEMPORAL VARIATIONS OF SULPHATE CONCENTRATIONS FOR THE WALLACE RIVER, NOVA SCOTIA.

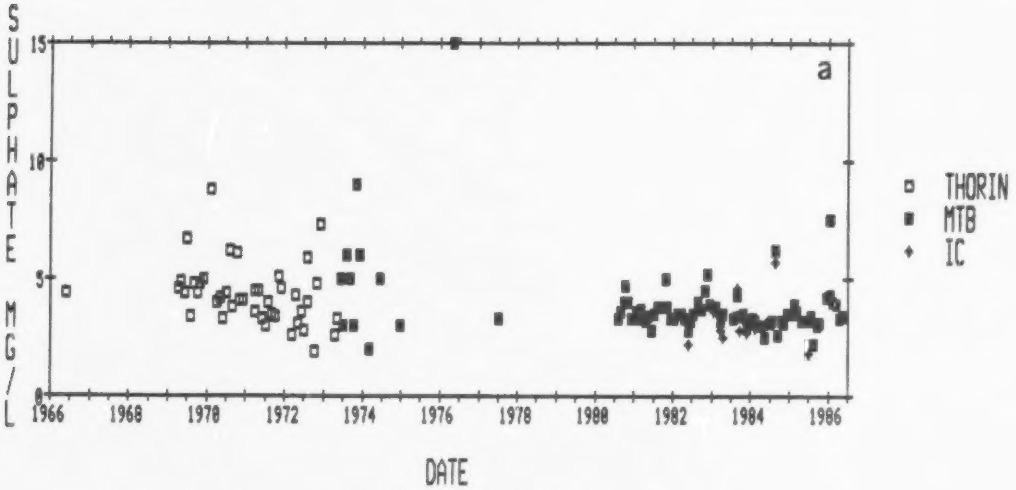
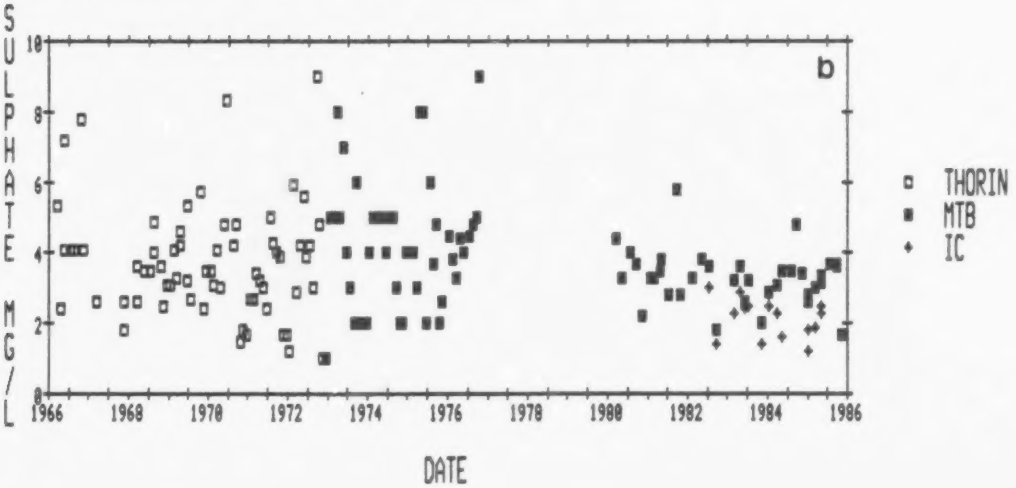


FIGURE 86b : TEMPORAL VARIATIONS OF SULPHATE CONCENTRATIONS FOR THE ISLE AUX MORTS RIVER, NEWFOUNDLAND.



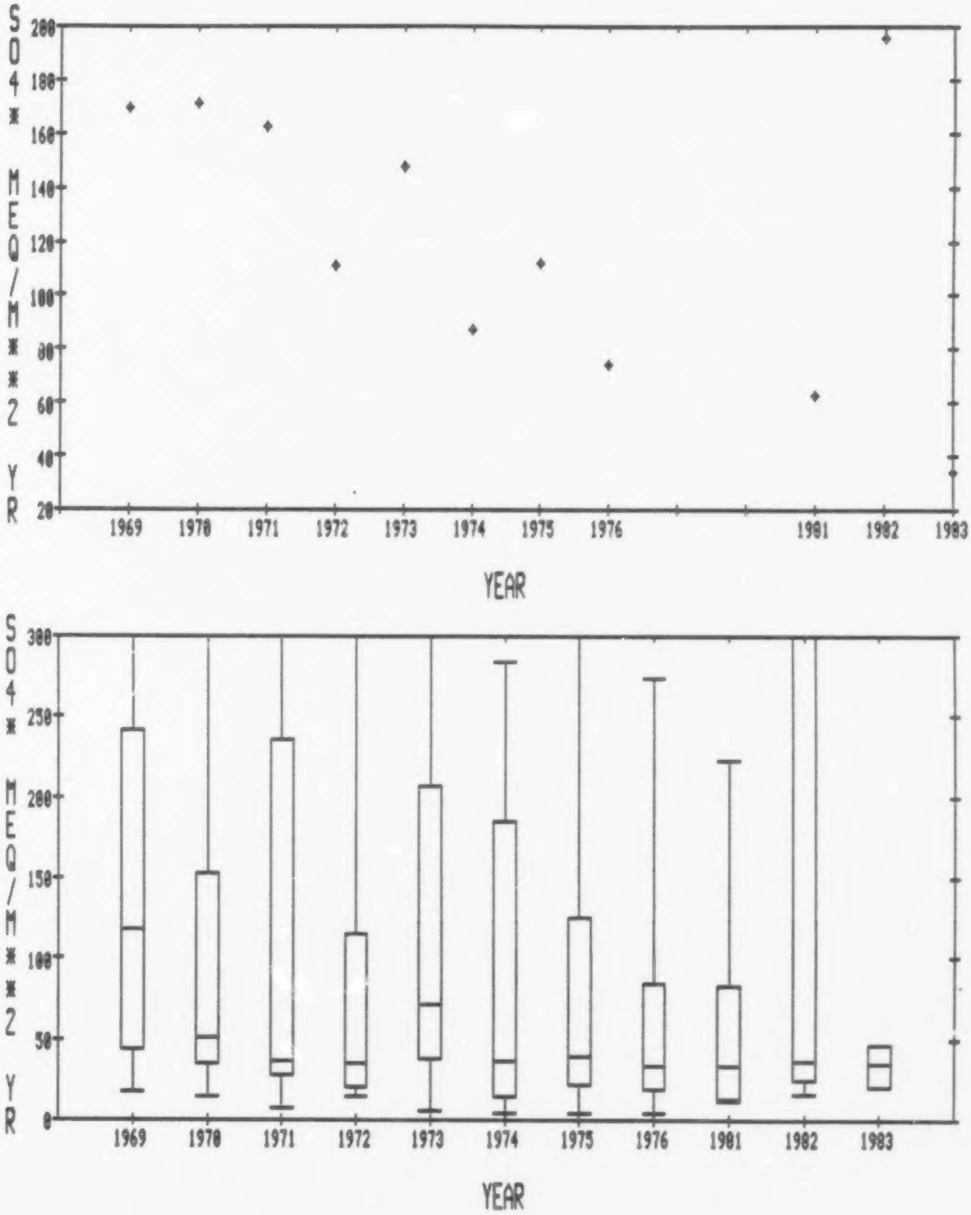


FIGURE 87(a,b): TEMPORAL CHANGES IN EXCESS SULPHATE ION EXPORT FOR THE ISLE AUX MORTS RIVER CALCULATED WITH DAILY MEAN DISCHARGE VALUES.

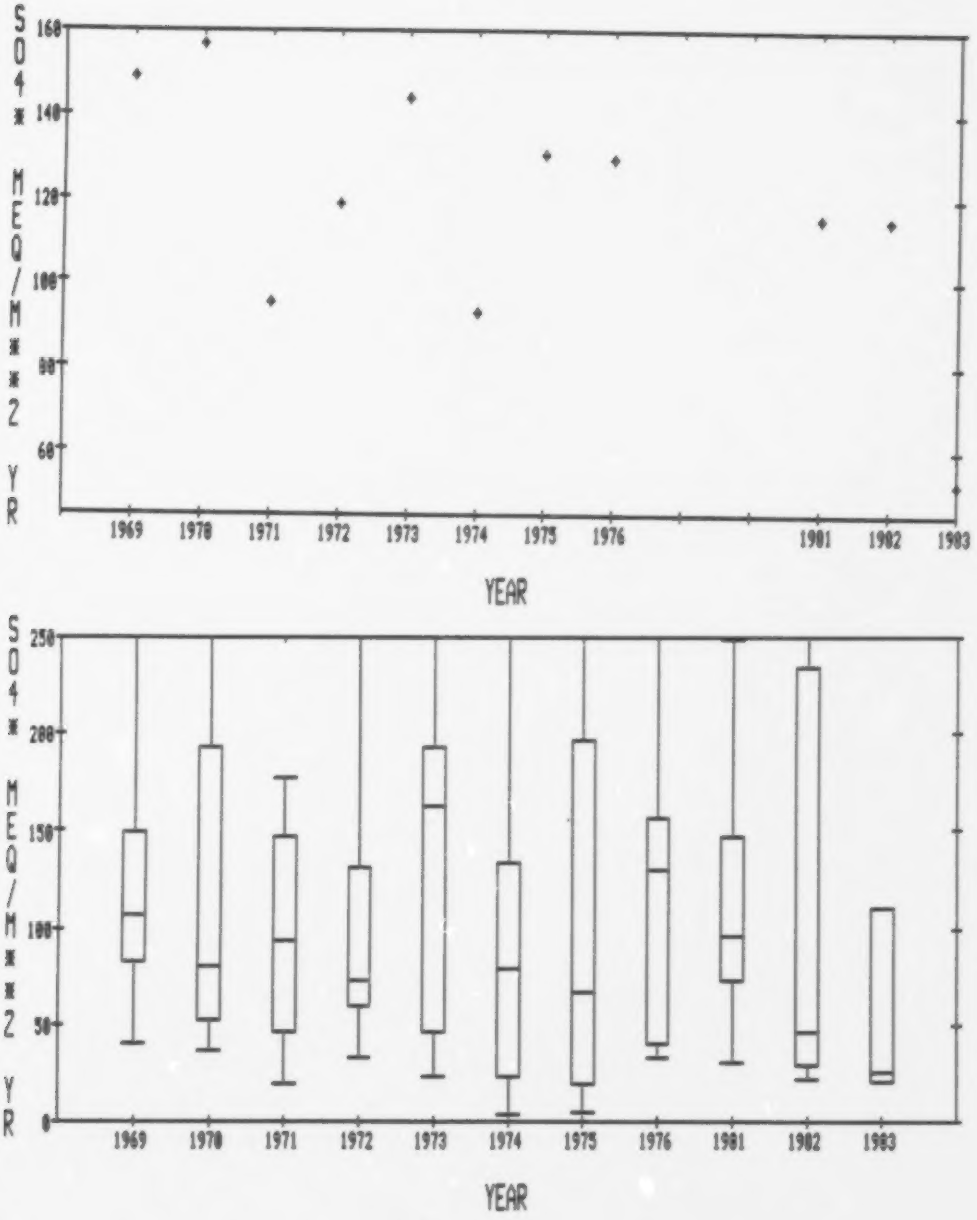


FIGURE 88(a,b):TEMPORAL CHANGES IN EXCESS SULPHATE ION EXPORT FOR THE ISLE AUX MORTS RIVER CALCULATED WITH MONTHLY MEAN DISCHARGE VALUES.

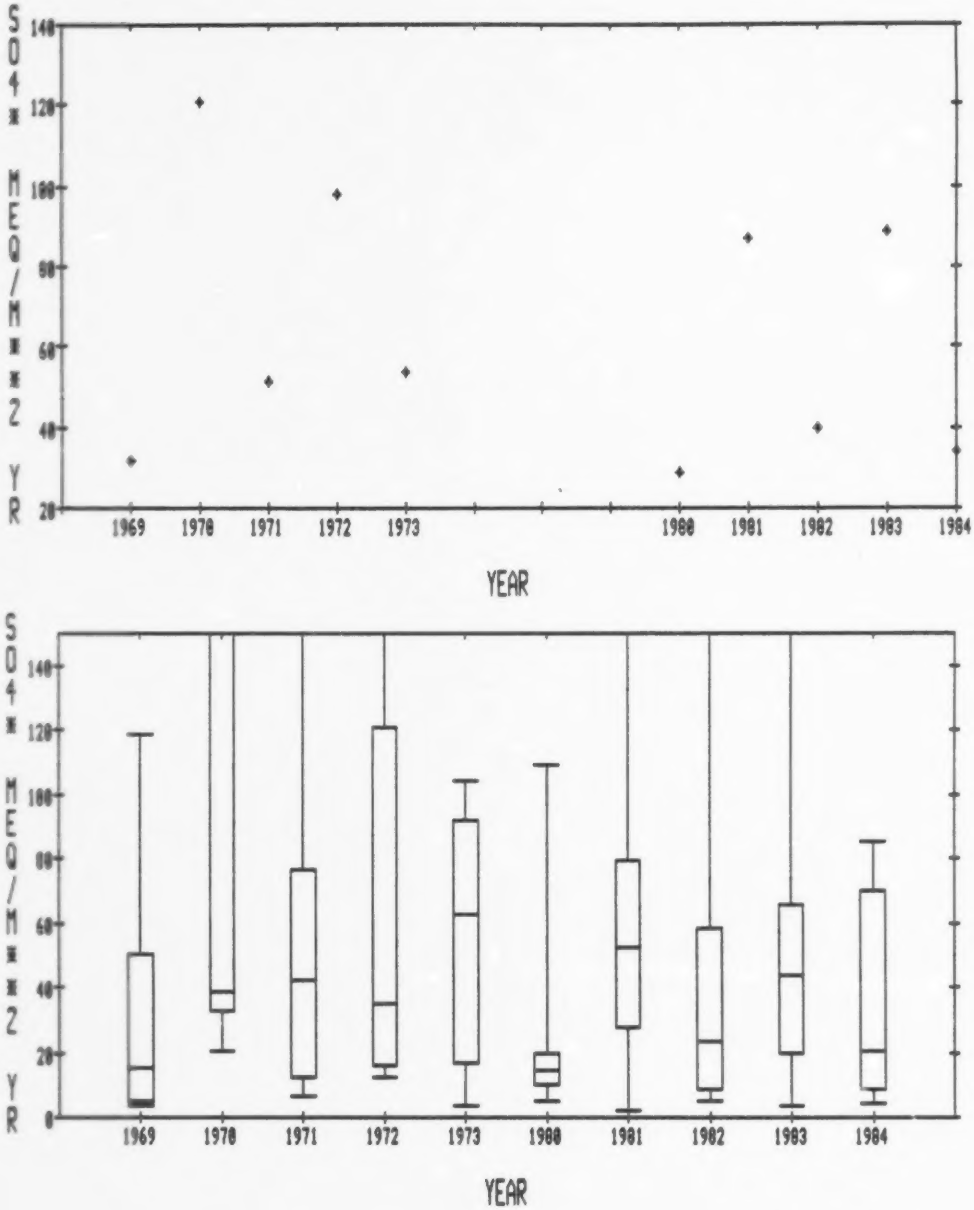


FIGURE 89(a,b): TEMPORAL CHANGES IN EXCESS SULPHATE ION EXPORT FOR THE WALLACE RIVER CALCULATED WITH DAILY MEAN DISCHARGE VALUES.

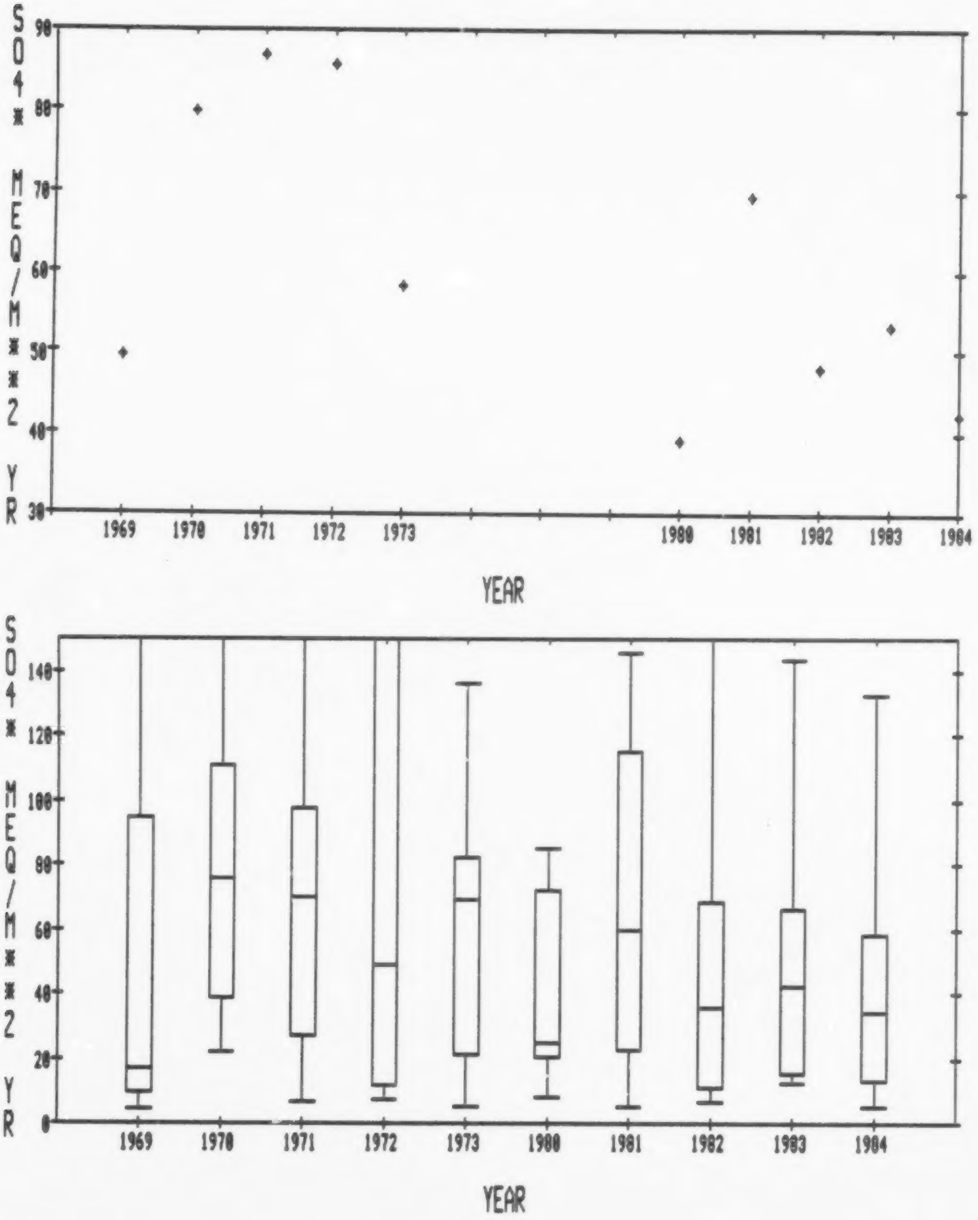
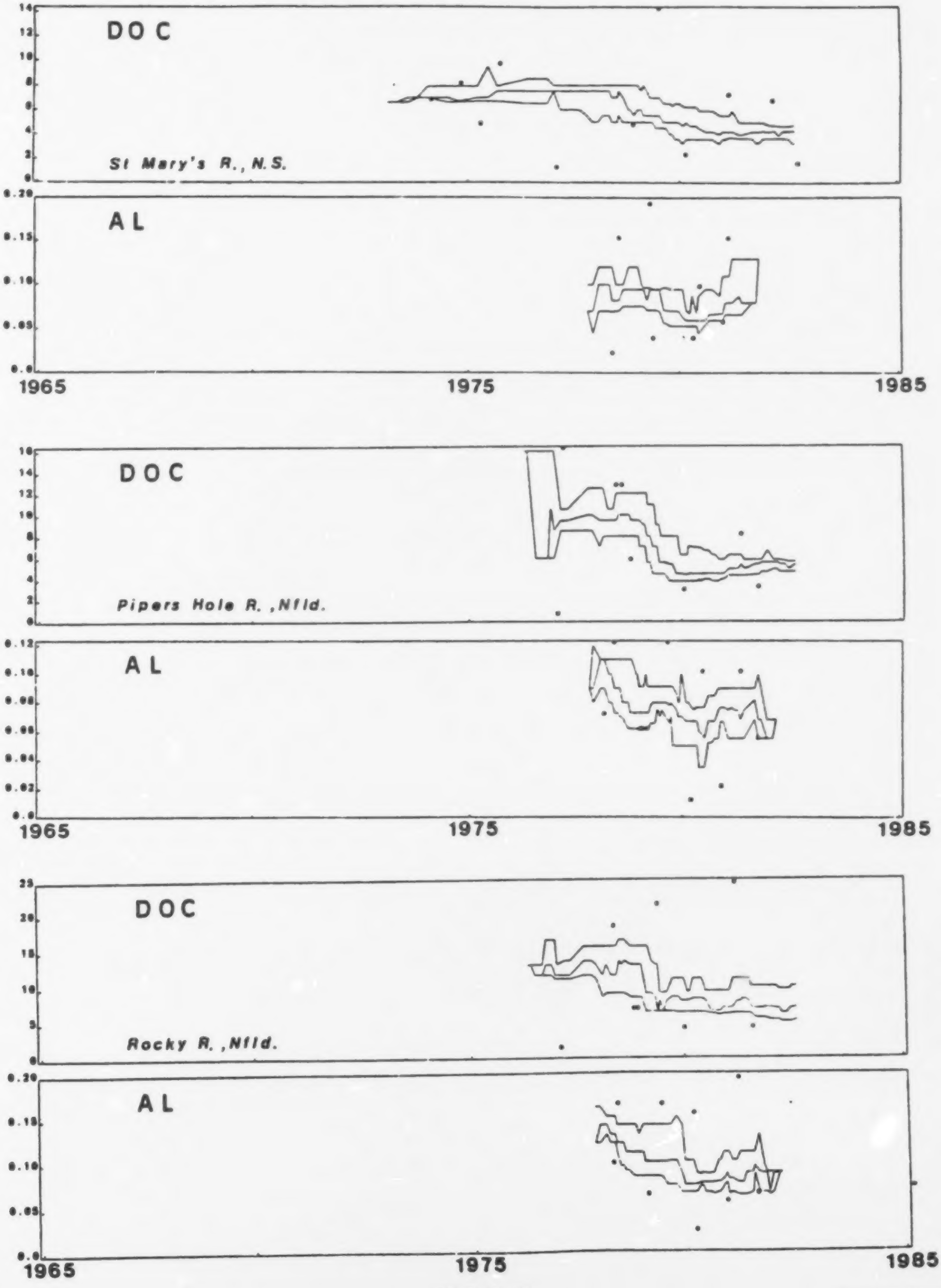


FIGURE 90(a,b):TEMPORAL CHANGES IN EXCESS SULPHATE ION EXPORT FOR THE WALLACE RIVER CALCULATED WITH MONTHLY MEAN DISCHARGE VALUES.

FIGURE 91: RUNNING BOXPLOTS OF EXTRACTABLE ALUMINIUM AND DISSOLVED ORGANIC CARBON CONCENTRATIONS FOR SELECTED RIVERS IN ATLANTIC CANADA .



APPENDIX 1

NOVA SCOTIA

Basin 01DA

Basin "01DA" is situated at the extreme southwestern tip of Nova Scotia falling between 43° 50′ - 44° 22′ latitude and 65° 57′ - 66° 14′ longitude. As the narrow longitude range would indicate, the basin extends along the coast being only 15 km from the sea at its most inland point. The geology of this basin is dominated by the Meguma group with nearly equal coverage by Halifax and Goldenville formations. A very small area of the basin at Cape St. Marys and south of Lake George is underlain by Upper Silurian White Rock Formation. The lake data from this basin are, with the exception of Lake George, underlain by the Meguma group with nearly equal distribution between the Halifax and Goldenville formations. The single river station is underlain by Halifax formation; however the majority of the basin drains Goldenville.

Basin 01DB

Basin "01DB" is situated to the north of basin "01DA" and has latitude and longitude ranges of 44° 17′ - 44° 45′ and 65° 20′ - 66° 7′ respectively. Although part of this basin bounds on the Fundy coast of Nova Scotia, it has a more extensive inland region than was observed for basin 01DA. This basin is more geologically diverse than 01DA, having significant areas underlain by seven formations. However, the water quality stations considered in this report are restricted to the Goldenville formation of the Meguma Series and Lower Devonian granitic and allied rock formations. These two formations dominate this basin and the water quality stations are distributed evenly between the two.

Basin 01DC

Basin "01DC" is situated in the northern portion of Annapolis and Kings County with the northern extreme bounding on the Bay of Fundy (44^{o} 35′ - 45^{o} 01′ lat.; 64^{o} 40′ - 65^{o} 45′ long.). This basin is also geologically diverse, having six formations with Lower Devonian granite covering the entire southern portion of the basin. The majority of the water quality lake stations are underlain by granite and allied rocks while the river stations and one lake station are all draining the Annapolis Group which is characterized by conglomerate, sandstone and shale. A single lake station is located near to the coast on a Triassic Series basalt and diabase bedrock.

Basin 01DD

Basin 01DD is situated in the eastern portion of Hants County and is bounded on the north and northeast by the Minas Basin. The co-ordinates of the basin span 44^{o} 47′ - 45^{o} 20′ latitude and 64^{o} 15′ - 64^{o} 52′ longitude. The southern part of the basin is underlain by Lower Devonian granite while the northern portion has five significant formations. The majority of the lake stations are situated in the granitic portion of the basin while the northern sites are underlain by Halifax formation of the Meguma Group or the Annapolis Group. One river station is also situated in the Annapolis Group while the other river station is underlain by the Horton Group and drains portions of Upper Devonian granite, Halifax formation and Upper Silurian Kentville formation.

Basins 01DE, 01EG, 01EH

Basins 01DE, 01EG and 01EH have been pooled together as there are few water quality stations in these basins. Basin 01EG is situated in the eastern sector of Lunenburg County and is bounded on the east by basins 01DE and 01EH and the south by Mahone Bay. Basin 01DE occupies the eastern portion of Hants County while Basin 01EH is situated in southeastern Lunenburg County and northwestern Halifax County. These three basins lie in an area bounded by 44° 22′ - 45° 7′ latitude and 63° 42′ - 64° 42′ longitude. Granitic and allied rocks predominate the geological structure underlying these three basins and the majority of the water quality lake and river sites are found on these formations. The southern portion of basin 01EG has Meguma Group, Halifax and Goldenville formation and localized areas of Windsor Group limestone and gypsum. Four of the river sites in this basin are situated on these three geological formations. The northeastern section of basin 01DE is quite diverse, having significant zones of Halifax and Goldenville formation and Windsor and Horton Groups. Two of the lake stations in the basin drain the Goldenville formation while one lake and two river stations are situated on the Windsor Group. The remaining seven 01DE sites are all located on Middle Devonian granite and allied rock.

Basins 01DH, 01DJ, 01DN

These three basins are located in northern Nova Scotia and have been combined due to the lack of water quality data from this area of the province. Basins 01DH and 01DJ are situated in northern Colchester County and are bounded on the south by the Minas Basin and on the north by Basin 01DN. Basin 01DN occupies the easter portion of Cumberland County and is bounded to the north by the Northumberland Strait. These three basins are situated in an area encompassed by the latitude and longitude ranges of 45° 30′ - 46° 00′ and 63° 00′ - 64° 15′. These three basins have very diverse geological structures having ten major formations. Four of the five lake stations are underlain by granite and allied rocks, while the fifth site is situated on Annapolis Group. The river sites are also found on these two formations, except for two stations in 01DN basin which are located on Cumberland Group of conglomerate, sandstone, shale, coal and minor limestone.

Basin 01EA

Basin 01EA is adjacent to Basin 01DA and occupies a southern portion of Digby County and northwestern Yarmouth County. This basin is situated from 43° 30′ - 44° 22′ latitude and 65° 30′ - 66° 8′ longitude and is bounded to the south by the Atantic Ocean. The geology of basin 01EA is dominated by granitic and allied rocks in the eastern portion and the Goldenville formation in the west and south. Interspersed with the Goldenville formation are regions of Halifax formation and Upper Silurian White Rock formation. The majority of the lake stations are underlain by Halifax and Upper Silurian formations, even though these geological structures are isolated to small areas along the western boundary of the basin. All of the rivers in this basin are situated on and drain the Goldenville Formation.

Basins 01EB, 01EC

Basin 01EB occupies the eastern extremes of Yarmouth County and the western part of Shelburne County. Basin 01EC is adjacent to basin 01EB and is situated in the eastern part of Shelburne County. The two basins are bounded to the south by the Atlantic Ocean and span latitudes and longitudes of 43° 15′ - 44° 15′ and 65° 07′ - 65° 50′ respectively. The geological structure of these two basins is dominated by granitic and allied rocks and the Goldenville formation. Some isolated areas particularily in basin 01EC are underlain by Halifax Formation of the Meguma Group. The lake stations are situated on both granite and Goldenville formation while the river stations are located mainly in areas underlain by granite.

Basin 01ED

Basin 01ED is situated in eastern Queens County and extends in the north into Digby and Annapolis County. This basin is situated between 43° 30′ - 44° 45′ latitude and 64° 40′ - 65° 37′ longitude and is bounded by the Atlantic Ocean on the south. The extreme northern portion of basin 01ED is underlain by granitic and allied rocks while the rest of the basin is dominated by Goldenville Formation. The central and southern portions of the basin also have distinct bands of Halifax Formation geological structures. All of the lake and river sites in this basin are situated in the northern portion in the vicinity of Kejimkujik National Park. These sites are rather evenly distributed amongst the three geological formations.

Basin 01EE

Basin 01EE is situated to the east of basin 01ED and occupies portions of Queens, Lunenburg and Annapolis Counties. This basin is bounded to the south by the Atlantic Ocean and is found between 44° 00′ - 44° 40′ latitude and 64° 20′ - 65° 20′ longitude. The north sector of the basin is underlain by granitic and allied rocks while there is a series of alternating bands of Halifax and Goldenville Formations. The majority of the sites in this basin are located in areas underlain by Halifax formation except for a series of lakes in the Molega and Ponhook Lakes area which are in the Goldenville formation. Only two of the sites are situated in the northern area of the basin which is underlain by granite.

Basin 01EF

Basin 01EF occupies western Lunenburg County and small portions of Annapolis and Kings Counties in the north. This basin has limited boundary with the Atlantic Ocean to the southeast and is situated from 44° 15′ - 44° 55′ latitude and 64° 15′ - 65° 5′ longitude. The northern portion of this basin is similar to the other southwestern Nova Scotia basins in that it is underlain by granitic and allied rocks. The southern portion of this basin is completely Meguma Group with the Halifax formation being far more abundant than the Goldenville formation. The lake and river water quality stations in this basin are situated on both granite and Halifax formation with about twice as many sites found on the southern Halifax formation.

Basin 01EJ

Basin 01EJ is located in the western part of Halifax County and encompasses the cities of Halifax and Dartmouth. This basin lies between 44° 25′ - 44° 55′ latitude and 63° 22′ - 63° 55′ longitude and is bounded to the southeast, south and southwest by the Atlantic Ocean. The dominant geological formation is granitic and allied rocks which underlay the southern part of the basin. The northeastern sector of the basin is dominated by the Goldenville formation intermixed with bands of Halifax formation deposits. The water quality stations in this basin are essentially equally distributed amongst the three geological formations.

Basin 01DG

Basin 01DG is elongated along the southwest-northeast axis and lies between 48° 45′ - 45° 30′ latitude and 62° 45′ - 63° 50′ longitude. The basin has a limited marine boundary with the Minas Basin in the north. This basin has a diverse geological structure having six different formations. The dominant structure is the Windsor Group which covers much of the north and central regions. This part of the basin also has significant areas of Horton and Riversdale Groups and a large band of Halifax formation. The south and southwestern parts of the basin are characterized by alternating bands of the Halifax and Goldenville formations. With the exception of three river and three lake sites found in the northern regions of the Windsor and Horton Groups, the 01DG sites are concentrated to the southern extremes of the basin. These sites are distributed between the Goldenville and Halifax formations with a 2:1 ratio in favor of the Goldenville geological structure.

Basins 01EK, 01EL, 01EM

Basins 01EK, 01EL and 01EM are situated in eastern Halifax County, along the eastern shore of Nova Scotia. These basins are bounded to the south by the Atlantic Ocean and lie between 44° 37′

- 45^{o} 15′ latitude and 62^{o} 25′ - 63^{o} 37′ longitude. These basins have a geological structure which is dominated by the Goldenville formation and granitic and allied rocks. The northeastern portion of basin 01EK has large areas underlain by the Windsor Group and the Halifax formation while the other basins have discrete bands of Halifax bedrock. All of the sites in these three basins are underlain by the Goldenville Formation with a couple of lake sites bordering on the Goldenville-granitic rock interface.

Basin 01EN

Basin 01EN is adjacent to basin 01EM and is situated in southeast Halifax County and southwestern Guysborough County. The co-ordinate range for this basin is 44^{o} 50′ - 45^{o} 30′ latitude and 61^{o} 50′ - 61^{o} 30′ longitude. The geology of basin 01EN is predominately the Goldenville Formation with some large Halifax Formation bands in the middle and southern extremes of the basin. A small area of granitic and allied rocks is located in the extreme northwestern sector of the basin. The water quality sites are generally located in areas of the Goldenville formation and a small number are underlain by the Halifax formation.

Basins 01EO, 01EP, 01ER

These three basins are at the eastern extreme of mainland Nova Scotia and cover most of Guysborough County and a small portion of southern Pictou County (45^{o} 00′ - 45^{o} 35′latitude; 61^{o} 15′ - 62^{o}

50′ longitude). These basins mark the end of the eastern shore and southern shore geology and thus the Goldenville, Halifax and granitic and allied rock formations are restricted to the southern portions of basins 01EO and 01EP. The dominant geological structure is the Horton Group which covers a large percentage of the northern portion of basins 01EO and 01EP and most of basin 01ER. The extreme northern portion of basin 01EO is underlain by Ordovician Series, Middle Devonian granites, Windsor Group and Arisaiq Group. The water quality sites from these basins are underlain by a mixture of geological structures including granite and allied rocks, Goldenville formation, Arisaiq Group and the Horton Group.

Basins 01FA, 01FB, 01FC

These three basins are located on the western side of Cape Breton Island and occupy most of Inverness County. These basins are geologically diverse having nine significant geological formations. Basins 01FA and 01FB are dominated by the Horton and Windsor Groups and all of the stations from these two basins are underlain by either of these two groups. The northern portion of basin 01FB and all of basin 01FC are characterized by granitic and allied rocks and the George River Group. Basin 01FC also has some isolated areas of Windsor, Horton and Riversdale Groups. The water quality stations in basin 01FC are generally located on the George River Group with the exception of two sites located in areas underlain by the Horton Group.

Basin 01FD

Basin 01FD is located in northeastern Cape Breton Island in the northern portion of Victoria County. This basin is bounded to the north and east by the Atlantic Ocean and lies between 46° 35′ - 47° 5′ latitude and 60° 15′ - 60° 45′ longitude. The dominant geology is granitic and allied rocks, and George River rocks. There are also isolated zones comprised of Horton and Windsor Group geological formations. The lake stations in this basin are with few exceptions underlain by granitic rocks or the George River Group. The river and two of the lake stations are located in areas underlain by Horton or Windsor Group geology; however the drainage basins for these sites are predominately granitic and allied rocks.

Basin 01FJ

Basin 01FJ is situated at the eastern extreme of Cape Breton Island and encompasses most of Cape Breton County. This basin is bounded to the north and east by the Atlantic Ocean and has co-ordinate ranges of 45° 40′ - 46° 20′ latitude and 59° 45′ - 60° 45′ longitude. The city of Sydney and a major coal mining and burning region are located in the northeastern portion of this basin. This basin is geologically diverse (9 geological formations) being dominated by the Pictou and Windsor Groups in the north and Cambrian rocks, granites and the Fourchu Group in the south. With the exception of two northern lake sites underlain by the Pictou Group, the lakes are clustered in Louisburg National Historic Park and are underlain by the Fourchu Group. The streams tend to be equally distributed between the Fourchu (4 stations) and the Windsor Groups (3 stations) except for a single station draining the Pictou Group.

Basin 01FH

Basin 01FH is located in southern Cape Breton Island and occupies nearly the entire area of Richmond County. This basin lies between 45° 25′ - 45° 52′ latitude and 60° 15′ - 61° 15′ longitude and is bounded to the north by Bras D'Or Lake and to the south by the Atlantic Ocean. This basin is also geologically diverse having seven formations of which the Horton Group and Cambrian and granitic rocks are dominant. The western part of the basin is underlain by large deposits of the Canso and Riversdale Groups. The majority of the lake and river stations in this basin are in areas underlain by the Horton Group. A few of the western lake and river sites are scattered amongst the Riversdale and Canso Groups.

NEWFOUNDLAND

Basins 02YA and 02YB

Basins 02YA and 02YB are situated in the extreme northern portion of the Great Northern Peninsula and are bounded to the west by the Strait of Belle Isle and to the east by the Atlantic Ocean. These two basins have co-ordinates ranging from 50° 40′ - 51° 45′ latitude and 55° 25′ - 57° 00′ longitude. The geology of basin 02YA is dominated by Ordovician Table Head Formation with minor deposits of Cambrian Hawke Bay Formation, Cambrian or Ordovician undivided rocks, Ordovician mafic or ultramafic rocks and Helikian rocks of the Long Range Complex. Basin 02YB has similar geological formations as observed for 02YA except that larger areas are covered by the Cambrian Hawke Bay Formation and Ordovician undivided rocks. Of the ten lake stations situated in these two basins, six are underlain by the Ordovician Table Head Formation and the additional four are located in an area of Ordovician mafic and ultramafic rocks.

Basins 02YC and 02YD

Basin 02YC is situated to the south of basin 02YA on the west coast of the Great Northern Peninsula. Basin 02YD is adjacent to basin 01YC and is bordered to the east by the Atlantic Ocean. These two basins lie between 50° 25′ - 51° 05′ latitude and 55° 55′ - 57° 25′ longitude. The geology of basin 02YC is dominated by a

Cambrian Hawke Bay Formation which occupies most of the central portion of the basin. There are also significant formations of granitic rocks of the Long Range Complex in the east and Ordovician Table Head Formations along the west coast. Basin 02YD includes the northern extremes of the Long Range Mountains and thus the entire middle and southern parts of the basin are characterized by Helikian Long Range Complex granitic rocks. The northeastern part of the basin has the western extremes of the Hawkes Bay, Table Head and the undivided Ordovician rock formations found to the north. The water quality stations located in these two basins are evenly distributed between the Long Range Complex granites and the Hawkes Bay Formation. Two stations in the northern portion of 02YD are underlain by the Table Head Formation.

Basin 02YE

Basin 02YE is situated to the south of basin 01YC and is bounded to the west by the Gulf of St. Lawrence. The basin is located in the southwestern portion of the Great Northern Peninsula between 49° 40′ - 50° 35′ latitude and 56° 50′ - 57° 55′ longitude. The eastern portion of this basin is underlain by Long Range Complex granites while Table Head Formation and undivided Ordovician rocks dominate along the western coast. In between the coastal and mountain geological structures are some isolated deposits of Hawkes Bay Formation rocks. There is an equal distribution of coastal and mountain sites in this basin with many of the stations located in Gros Morne National Park in the southern part of the basin. Of the fourteen sites located in this basin, eight, four and two are underlain by Long Range Complex granites, undivided Ordovician rocks and the Table Head Formation respectively.

Basins 02YF and 02YG

Basin 02YF is situated on the eastern side of the Great Northern Peninsula and is bounded to the east by White Bay. Basin 02YG is located to the south of basin 02YF and surrounds the south and eastern perimeter of White Bay. These two basins encompass an area with co-ordinates of 49° 20′ - 50° 35′ latitude and 56° 05′ - 57° 45′ longitude. Basin 02YF is almost entirely dominated by the Long Range Complex of granitic and metamorphic rocks except for a small isolated Ordovician Table Head formation located in the extreme southwestern part of the basin. The western sector of basin 02YG is dominated by the Long Range Complex while the eastern part of the basin has a diverse geological structure made up of the Cambrian Fleur De Lys group, Devonian granites, Carboniferous Anguille Group, White Bay Silurian Rocks and Ordovician Table Head Formation. All of the water quality stations in basin 02YF and three sites in 02YG are underlain by the Long Range Complex of granitic and metamorphic rocks. A site in the south of basin 01YG is situated on Devonian granite and another eastern site is underlain by the Cambrian Fleur De Lys group.

Basin 02YH

Basin 02YH is situated on the western coast of Newfoundland and is bounded to the east by the Gulf of St. Lawrence and to the south by the Bay of Islands. This basin lies between 49° 00′ - 49° 45′ latitude and 57° 30′ - 58° 10′ longitude. The northeastern section of this basin is underlain by the southern extreme of the Long Range Complex of granitic and metamorphic rocks, while the southern portion of the basin is dominated by Ordovician Table Head Formation and Cambrian undivided rocks. In the western part of the basin there are isolated areas of Ordovician age granites, intermediate to mafic intrusive rocks and mafic to ultramafic rocks, while in the southeast there are small areas underlain by Cambrian Hawke Bay and Fleur de Lys formations. The water quality stations in this basin are generally found in areas underlain by the Long Range Complex or the Ordovician Table Head formations. Two sites near Trout River are underlain by Ordovician age granites, intermediate to mafic intrusive rocks and mafic to ultramafic rocks and a simple site to the north of Baker Brook is situated in a region of Ordovician undivided rocks.

Basin 02YK

Basin 02YK is elongated in the northeast-southwest direction and includes Grand Lake which is the largest freshwater feature on the island. This basin is essentially landlocked and lies between 48° 30′ - 49° 30′ latitude and 56° 30′ - 58° 15′ longitude. As was the case for basin 02YH, basin 02YK also has a high geological diversity. The eastern portion of the basin is predominately underlain by Devonian granites and related rocks with some isolated regions of Cape St. John Group of Silurian rocks in the northeast and Glover Formation material in the southeast. To the west of Grand Lake, the geology is dominated by Carboniferous Anguille and Codroy Groups except in the southwest where Cambrian rocks and Orodicivian Table Head Formations dominate. The majority of the sites in this basin are located on Devonian granites and related rocks while the rest are distributed amongst Cape St. John Silurian rocks, Carboniferous Anguille Group and Cambrian rocks.

Basin 02YL

Basin 02YL is situated between basins 02YH and 02YK and incorporates the Humber River drainage. This basin has limited coastal contact and is situated from 48° 40′ - 49° 45′ latitude and 57° 00′ - 58° 15′ longitude. The northwestern part of the basin is underlain by Long Range Complex granites and metamorphic rocks while the northeast and central portions of the basin are on Carboniferous Anguille Group. The southern part of the basin has a diverse geology with alternating bands of four formations of Cambrian and Ordovician rocks. Five of the nine lake stations in this basin are situated on the Long Range Complex of granite and metamorphic rocks while the additional three sites are underlain by the Anguille Group or Cambrian rocks. The river stations in this basin are situated on Carboniferous Anguille Group bedrock.

Basin 02YN

Basin 02YN is a northeast-southwest oriented inland basin which encompasses the Exploits River Basin, and Red Indian Lake. This basin has a co-ordinate range of 47° 50′ - 49° 05′ latitude and 56° 25′ - 58° 10′ longitude. The basin to the west of the Exploits River is dominated by Devonian granites and metamorphic rocks with minor deposits of Silurian rocks and the Roberts Arm Group. To the east of Red Indian Lake there are large deposits of Ordovician volcanic-slate-greywacke facies and Ordovician and Silurian rocks with granitic and basic intrusions. Several of the water quality stations in this basin are situated in the Red Indian Lake system which drains Devonian granites, Silurian rocks and the Ordovician volcanic-slate-greywacke facies. The other stations tend to be evenly distributed amongst the four dominant geological structures of this basin.

Basin 02YM

Basin 02YM occupies most of the Baie Verte Peninsula. It is bounded to the north and northeast by Notre Dame Bay and the Atlantic Ocean, to the west by basin 01YG and to the south by basin 02YK. The basin lies between latitudes 49° 15′ - 50° 05′ and longitudes 55° 30′ - 56° 45′. The basin geology is comprised of three major formations. The southeast and northeast are Springdale and Cape St. John silurian rocks. The east has the Headlands Group Ordovician rocks whilst the west is dominated by areas of granitic rocks. There are eight sites located in this basin divided 5 - 3 between the Silurian and granitic rocks.

Basin 02YO

This is the Exploits River Basin from the outflow of Red Indian Lake to the mouth on the Bay of Exploits. It is the largest hydrometric basin in Newfoundland lying between latitudes 48° 15′ - 49° 50′ and longitudes 54° 50′ - 57°. The geology of this basin is quite complex with Ordovician, Silurian and Ordovician-Silurian with two small belts of granitic rocks in the southern part of the basin. The east and northwest are comprised of Devonian granites and quartz rocks. The central part of the basin is the Botwood Group Silurian rocks and the northeast is comprised of Ordovician rocks. There are 14 sites in this basin, distributed fairly evenly between the various geological formations.

Basin 02YP

Basin 02YP is located along the south shore of Notre Dame Bay. The basin lies between latitudes 48° 55′ - 49° 50′ and longitudes 55° 10′ - 56° 45′. The eastern portion ($\simeq$ 50%) of the basin is comprised almost entirely of the Wild Bight Group of Ordovician rocks. A small belt of granitic rocks is located in the middle of the Ordovician rocks. Three sites are located on this belt. The western half of the basin from south to north is comprised of granitic, Silurian and Ordovician Silurian rocks. Two sites are located in this half of the basin, one on Silurian rocks and one on granitic rocks.

Basin 02YQ

This is the Gander River Basin, it is a long narrow basin with a southwest to northeast orientation. It is situated between latitudes 48° 10′ - 49° 25′ and longitudes 54° 20′ - 56°. Running the length of the central part of the basin is an ordovician formation, the Gander Lake Group. To the southeast of this formation is a belt of granitic rocks. There are also two small areas of granitic rocks to the southwest and west. The remainder of the basin is comprised of Ordovician and Ordovician Silurian rocks. There are 12 sites located in this basin distributed evenly between the various formations.

Basin 02YR

This basin on the northeast corner of the island is bounded on the north and east by the ocean, on the west by the Gander River Basin and on the south by the Terra Nova River Basin. It is situated between latitudes 48° 20′ - 49° 25′ and longitudes 53° 30′ - 55°. The geology is composed almost entirely of Ordovician (Gander Lake Group) and coarse-grained porphyritic biotite granite rocks with the granitic rocks primarily in northern and eastern parts of the basin. There are 12 sites in this basin equally divided between the ordovician and granitic formations.

Basin 02YS

Basin 02YS is the Terra Nova River Basin. It is situated on the east coast of the island on Bonavista Bay between latitudes 48° - 48° 45′ - and longitudes 53° 40′ - 55° 20′. It is bounded to the north by hydrometric basin 02YR, the west by 02YQ and the south and southeast by 02ZF, 02ZH and 02ZJ. The geology of this basin is complex with ordovician Gander Lake Rocks at the western end of the basin, then belts of granitic rocks, Hadrynian Musgravetown Group, Love Cove Group and Connecting Point Group rocks. There is also a small area of Cambrian rocks in the southeast of the basin. There are 55 sites located in this basin. All the sites are located in Terra Nova National Park with the exception of 7 which are evenly spaced over the west and central parts of the basin.

Basin 02ZA

Basin 02ZA is located in the southwest corner of the island along the shore of St. Georges Bay. It is situated between latitudes 47° 30′ - 48° 35′ and longitudes 57° 40′ - 59° 20′. The basin is oriented from southwest to northeast and divided in two halves lengthwise by the geology. The northwestern geology is composed of Carboniferous rocks whereas the southeastern half is mostly Ordovician Silurian with some granitic intrusions. There are 11 sites in this basin, two are located on the Carboniferous rocks and the remainder on the Ordovician Silurian rocks.

Basin 02ZB AND 02ZC

Basin 02ZB is the easternmost of the south coast hydrometric basins. Located between latitudes 47° 35′ - 48° 5′ and longitudes 58° - 59° 5′ the geology of the basin is composed almost entirely of granitic bedrock. There are three sites in the central part of the basin.

Basin 02ZC is located just to the east of basin 02ZB, situated between latitudes 47° 35′ - 48° 20′ and longitudes 56° 50′ - 58° 5′. The basin geology is also composed of mainly granitic rocks and there are 8 sites evenly distributed across the basin.

Basin 02ZD and 02ZE

Basin 02ZD is located along the south coast to the east of basin 01ZC. Located between latitudes 47° 25′ - 48° 30′ and longitudes 56° 15′ - 57° 10′, the basin geology is similar to that of basin 02ZC except for a belt of silurian rocks to the east of the basin centre. There are 6 sites in this basin evenly spaced and all on granitic bedrock. Basin 02ZE is to the east of basin 02ZD, situated between latitudes 47°30′ - 48°30′ and longitudes 55°15′ - 56°30′. To the west, north and northwest, the basin geology is composed of Devonian granitic and Ordovician Silurian rocks. In the south and east are Ordovician rocks of the upper and lower Baie D'Espoir Group. There are 12 sites in this basin, all but 2 of which are evenly spaced on the granitic rocks to the north and west.

Basin 02ZF

Basin 02ZF is located on the south coast of Newfoundland to the east of basin 02ZE and along the north shore of Fortune Bay. Located between latitudes 47°20′ - 48°20′ and longitudes 54°40′ - 56°10′. The north, east and central areas (approx. two thirds of the basin) are composed entirely of granitic rocks. The western part of the basin is an extension of the Ordovician rocks of the Baie D'Espoir Group from Basin 02ZE. In the south, there is a mixture of Silurian, late Hadrynian, Cambrian and Upper Devonian rocks. There are 13 stations located in this basin, mostly distributed across the granitic and Ordovician rocks.

Basin 02ZG, 02ZH, 02ZJ

Basin 02ZG encompasses the Burin Peninsula. Located between latitudes 46°50′ - 47°40′ and longitudes 54°30′ - 56°00′ it is composed almost entirely of Hadrynian volcanic rocks. Only one site is located in this basin close to the northern end. Basin 02ZH is situated at the head of Placentia Bay to the north of basin 02ZG, east of 02ZF and south of the Terra Nova River Basin 01YS. The basin is located between latitudes 47°25′ - 48°10′ and longitudes 53°55′ - 54°50′. The geology is quite varied with granitic rocks to the west and northeast, Hadrynian volcanic rocks in the south and Hadrynian rocks of the Love Cove Group and Musgravetown Group in the north. There are 6 sites located in this basin divided between the Pipers Hole and Come-by-Chance River Basins. Basin 02ZJ is located along the western shore of Trinity Bay and is immediately east of basins 02YS and 02ZH. It is situated between latitudes 47°40′ - 48°40′ and longitudes 53°00′ - 54°10′. The geology is composed of Hadrynian Musgravetown Town and Connecting Point Group rocks with two small belts of Cambrian rocks in the central part of the basin. There are 6 sites located in this basin.

Basin 02ZK and 02ZL

These two basins form the western half of the Avalon Peninsula. Situated between latitudes 46°45′ - 48°10′ and longitudes 52°50′ - 54°10′ the basin geology is almost entirely composed of Hadrynian rocks of the Musgravetown and Hodgewater Groups. There are 21 sites evenly distributed across these basins.

Basins 02ZM and 02ZN

These two basins form the eastern half of the Avalon Peninsula. Located between latitudes 46°40′ - 47°50′ and longitudes 52°40′ - 53°45′ these basins are composed of Hadrynian Conception Group rocks except for a small belt of Helikian rocks in the northwest of basin 02ZM. There are 8 sites in these basins, 7 in 02ZM and 1 in 02ZN.

New Brunswick

Almost one half of the province of New Brunswick consists of Pennsylvanian red to grey sandstone, conglomerates and siltstones. This triangular shaped area covers completely basins 01BL, 01BR, 01BO, 01BN, 01BS, 01AN, 01AO, 01BT, and parts of 01AM and 01AP. Only 1 site is located in this area, in the southeast corner (basin 01BT).

In the northwestern part of the province, north of latitude 46^{o}, comprising all of basins 01AD, 01AF, 01BB, 01BA, 01BC, 01BE, 01BJ, 01BK, 01BQ, 01AH, 01BP, 01AG, 01BM, 01AJ, 01AL and half of 01AK there are only 3 sites. One of these sites is located on granitic rocks in basin 01BM the other two are located on Ordovician rocks along the US/Canadian border, one in basin 01AF and the other in basin 01AG. This part of the province is characterized by various mixtures of Devonian, Silurian and Ordovician rocks. Only the North Central area basins 01BM and 01BP are located on granitic type rocks.

The remaining sites in New Brunswick are all located in the southwest, 5 in the southern half of basin 01AK, 16 in basin 01AQ and 12 in basin 01AR.

Basin 01AK

This basin is located along the western boundary of the province and is part of the Saint John River basin. Situated between latitudes 45°40′ - 46°20′ and longitudes 66°40′ - 67°45′ the bedrock geology is composed of mostly granitic rocks south of latitude 46° and Ordovician Silurian rocks to the north. All the sites are in the southern part of the basin on the granitic rocks.

Basin 01AR

Basin 01AR is located in the southwest corner of the province. The St. Croix River which is the US/Canada Boundary forms the western limit and the Bay of Fundy is the southern limit. It lies to the south of basin 01AK and adjacent to basin 01AQ. Situated between latitudes 44°50′ - 45°50′ and longitudes 66°50′ - 67°45′ its geology is quite mixed. There are Devonian granites at the north and south ends of the basin. In the centre the rocks are mostly Ordovician and Silurian. The 12 sites in this basin are almost all located on the granitic rocks.

Basin 01AQ

This basin is located along the shore of the Bay of Fundy to the east of and adjacent to basin 01AR. The basin is located between latitudes 45°05′ - 45°50′ and longitudes 66°10′ - 67°25′. The geology is dominated by a large area of granitic rocks in the center, Ordovician and Silurian rocks to the north and a complex mixture of rocks mostly Silurian and Devonian along the Bay of

Fundy shore. The sites in this basin are almost all located on the granitic rocks.

Labrador

Basins 03ND, 03NF and 03NG

These three basins cover a large area in northern Labrador. Situated between latitudes 54°8′ - 57°30′ and longitudes 58°30′ - 64°15′ the geology of these basins is quite complex. The northern part of these basin areas consists of Paleohelikian granitic type rocks in the east and Aphebian granitic rocks in the west. In the southern part there are belts of various Aphebian rocks in the south east. Moving westwards there are successively large belts of Archean granites, Paleohelikian granites, Helikian rocks (containing limestones) and finally a belt of Aphebian granitic rocks.

There are 16 sampling sites located in these basins, 1 in basin 03ND, 3 in basin 03NF and 12 in basin 03NG.

Basins 03PA, 03PB

These two basins are located to the north of the Churchill River drainage basin. A large section of basin 03PA is submerged and forms part of the Smallwood Reservoir. Situated between latitudes 53°30′ - 54°50′ and longitudes 59°55′ - 65°10′ this area has an east-west axis. The southern and western portions consist of Helikian and Paleohelikian rocks (mostly granitic). The northern half of the eastern basin 03PB may include some stromatolitic limestone. There are 2 sites located in basin 03PA and 9 sites located in basin 03PB.

Basins 03OA, 03OB, 03OC, 03OE

These basins are located in the south-western part of Labrador and together comprise the Churchill River drainage basin. This is a large region located between latitudes $51^{o}35'$ - $55^{o}25'$ and longitudes 60^{o}-$67^{o}45'$. The extreme west of this region is dominated by a belt of Archean Pyroxene Granulite rocks. To the east of this formation are belts of various Aphebian or earlier rocks which include some dolomite and limestone. In the eastern part of the region, the rocks are mostly Helikian and Paleohelikian. There are 13 sites located across this region.

Basins 02VC, 02WB, 02XA, 02XB and 02XC

These basins are located along the southern border between Labrador and Quebec. They include the headwaters of the Romaine Natashquan, Little Mecatina, St. Augustin and St-Paul Rivers. This area is bounded by latitudes 52^{o}-$52^{o}55'$ and longitudes $57^{o}10'$ - $64^{o}10'$. The geology of these basins is homogeneous and is composed of Helikian, Paleohelikian and Neohelikian rocks, mostly granitic in nature. There are 41 sites distributed across these basins.

Basins 03QA, 03QB, 03QC

These basins are located in the southeast corner of Labrador. The Atlantic Ocean forms the eastern boundary, to the south is the divide between the basins draining to the Atlantic Ocean and those draining to the Gulf of St. Lawrence. To the north is lake Melville and basin 03PC and in the west is basin 03OE. Situated between latitudes 52° - $54^{\circ}20'$ and longitudes $55^{\circ}40'$ - $61^{\circ}5'$ the geology of these basins is comprised almost entirely of Helikian, Paleohelikian and Neohelikian rocks, mainly granites. There are 27 sampling sites in these basins.

Basin 03PC

This basin situated between latitudes $53^{\circ}35'$ - $54^{\circ}55'$ and longitudes $57^{\circ}10'$ - $60^{\circ}40'$ is located midway up the coast of Labrador. It is bounded on the south by basin QB and lake Melville, to the north by basin 03NG land to the west by basin 03PB. The basin geology is dominated by a large formation of Helikian rocks, mainly garnetiferous biotite-quartz-feldspar paragneiss. To the northeast of this formation is a belt of Aphebian rocks mostly granites, and to the south and southwest mostly Helikian granites with two small formations of Hadrynian sandstones. There are 17 sites located in this basin.